**Shifting the Frontiers of Early Modern Science:
Astronomers, Botanists, and Engineers in Viceregal New
Spain during the Habsburg Era, 1535-1700**

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A thesis submitted to Victoria University of Wellington in fulfilment of the
requirements for the degree of Doctor of Philosophy in 2017.

Contents

Contents	1
List of Tables	2
List of Figures	3
Abstract	5
Acknowledgments.....	7
Introduction.....	9
Chapter 1 A Rare Manuscript in the Age of Print: Francisco Hernández's <i>Natural History of the Plants of New Spain</i> (1576)	35
Chapter 2 The First Large-Scale Astronomical Expedition (1583-1590): Jaime Juan and Francisco Domínguez y Ocampo	62
Chapter 3 A Culture of Debate and Publication among Mexico City's Hydraulic Engineers (1606-1640).....	90
Chapter 4 Astronomy and Optical Instruments in Mexico City-Puebla: Scientific Networks in Spanish America & Europe (1611-1692).....	128
Chapter 5 The Circulation of Scientific Books to and from New Spain (1550-1700)	
176	
Conclusion	216
Bibliography	226

List of Tables

Table 0.1: Nodes in Knowledge Networks of Spanish America by 1600	30
Table 1.1: Major Sixteenth-century Authors of American Natural Histories.....	39
Table 2.1: Herrera’s Book Selections for the Academy of Mathematics Curriculum.	69
Table 2.2: List of Instruments as named and described in the <i>Instrucciones</i>	72
Table 2.3: Jaime Juan’s Report – The Seven Propositions (1584)	83
Table 3.1: Visual Representations of Mexico City, 1521-1755.....	104
Table 3.2: Desagüe Budget Proposal, 1604.	114
Table 3.3: Selection from Adrian Boot's Library, 17 September 1637	118
Table 4.1: Diego Rodríguez's Extant Writings, 1638-1652.....	144
Table 5.1: Mathematics Books Printed in Mexico City before 1600	186
Table 5.2: Hans Sloane's Collection of Mexican Works (includes works produced in New Spain but published in Europe)	188
Table 5.3: Selection of Mexican Imprints that arrived in Spain during the 16th and 17th Centuries	191
Table 5.4: Selected Works on Mathematics and the Sciences published in Mexico City 1553-1700	193
Table 5.5: Books produced in Mexico City that Appear in the “Memorias de Libros” with number of Appearances	194
Table 5.6: Summary of 25 Book Lists submitted to the Mexican Inquisition, 17th century.....	199
Table 5.7: Selection of 348 works from Melchor Pérez de Soto’s 1,000+ book library: Authors, Editions, and Subject Areas	206

List of Figures

Figure 3.1: La Gran Ciudad de Temixtitán, c. 1521	103
Figure 3.2: Uppsala (Santa Cruz) Map, c. 1540	103
Figure 3.3: Plan of Mexico City 1628 by Juan Gómez de Trasmonte.....	104
Figure 3.4: Lake Texcoco, c. 1519	115
Figure 4.1: Astrologer Juan Ruiz's petition for a licence to publish his Pronóstico of 1660. AGN Instituciones Coloniales, Inquisición 12500 Volumen 670, folio 198...	136
Figure 4.2: Title page to Sigüenza y Góngora's Almanac of 1690, in Sigüenza's hand. AGN Instituciones Coloniales, Inquisición 12500 Volumen 670, folio 200.....	137
Figure 4.3: "Diario y Discursos Astronómicos hechos por Gabriel López de Bonilla" AGN Instituciones Coloniales, Inquisición 12500 Volumen 670, folio 260.....	138
Figure 4.4: Kino's evocative titlepage invoking the favour of more than one patroness., Biblioteca Nacional de México, Fondo Reservado, RFO 082.1 GUE	131
.....	155
Figure 4.5: Last page of Favián's letter to Kircher, 2 February 1661, Tomo IV 141r. Archivio Pontificia Università Gregoriana (Rome).	166
Figure 4.6: Vol.1 of Kircher's <i>Musurgia Universalis</i> gifted by the author to Alexandro Favián. Biblioteca Palafoxiana, Puebla (Mexico), PAFX NX 290 K5 t.1.....	166
Figure 4.7: Vol.II of the <i>Musurgia Universalis</i> by Kircher gifted to Alexandro Favián PAFX Q173 K5 t.2.	167
Figure 4.8: Cardinal Fernando Niño de Guevara (1541–1609).	169
Figure 4.9: Luis de Velasco, Viceroy of New Spain (c. 1534-1617).....	170
Figure 4.10: Poet Francisco de Quevedo (1580-1645).	170
Figure 4.11: Diego Carrillo de Mendoza y Pimentel, Viceroy of New Spain (1570-1631).	171
Figure 4.12: Astronomer-Poet Carlos de Sigüenza y Góngora (1645-1700).....	171
Figure 5.1: "Record of the books which I take with me...upon these...galleons for Don Manuel de Bañuelos y Sandoval" 1669, AGI Contratación 674, ff.11-12.	184
Figure 5.2: Portrait of Sor Juana Inés de la Cruz (1648-1695) in her personal library.	193

Figure 5.3: “We Inquisitors Against Heresy...” AGN Instituciones Coloniales, Inquisición 12508, Vol. 678 f.220	197
Figure 5.4: Inventory of Jesuit books at San Pedro y San Pablo made upon the Expulsion of the Society in 1767. AGN Instituciones Coloniales, Temporalidades 29989, Tomo 230 f.1.....	198
Figure 5.5: Adrian Boot’s library inventory. AGN Inquisition 12213, Vol. 383, f.10	203

Abstract

This doctoral thesis offers a big-picture view of the material and cultural history of science in colonial Latin America. It argues that science in the Viceroyalty of New Spain can be best understood not as isolated from centres of European culture, but rather as a productive extension of Old World and Indigenous techniques for observing and quantifying nature. Moreover, it also shows that Mexico City quickly became a central node in the production and funding of science within the Spanish Empire, rather than being peripheral to early modern scientific discourse. It examines the nerve centre of Spain's overseas territories, the viceregal capital of New Spain, as a hub not only of funding but also of vibrant activity for Spanish and Novohispanic science from 1535 to 1700.

Current historians of Spanish and Spanish-colonial science have demonstrated that, in contrast with depictions in older histories of early modern science, Spain was an active producer of technologies of discovery and natural resource extraction as well as works on theoretical and applied mathematics. During the sixteenth and seventeenth centuries, the Spanish Crown and other private corporate bodies—including the religious orders—supported the production of new forms of knowledge. I will refer to these throughout as “science” and to its practitioners as “scientists.”

Scientists who feature prominently in this thesis set precedents for later scientific endeavours in Latin America and Europe. Sixteenth-century botanist Francisco Hernández, cartographer Francisco Domínguez y Ocampo, and astronomer Jaime Juan established some of the first large-scale observations and records of an expansive New Spain. In the following years a diverse set of seventeenth-century hydraulic engineers fielded a variety of solutions to a complex set of topographical and political issues in the viceregal capital. At the same time, a lively group of astronomer-mathematicians contributed to an increasingly global network of scientific discourse.

Many of these scientists and intellectuals owned notable personal libraries. This thesis examines the implications of mobile books—locally-produced as well as

European—as they contributed to the production of new knowledge in the Americas, Asia, and Europe. Powerful Spanish and *criolla* women patronized or supported the promulgation of scientific writings in New Spain. Additionally, indigenous authors disseminated the concepts of early modern science to their readers within colonial-era Nahua chronicles. Hobbyists also interacted with professional and well-known scientific thinkers at local discussion clubs or via correspondence and improvised their own instruments based on available texts. Local book printers and authors of popular early modern science works are also included in this investigation as they played key roles within the social networks of science.

This thesis relies on archival manuscript sources while synthesizing the rigorous scholarship of many specialists in order to tell the story of how a major sixteenth-century Spanish colonial city possessed the resources to engage in a variety of early modern scientific undertakings. It re-examines documents concerning the history of science in New Spain in order to ask new questions about the role of scientists' instruments, personal book collections, and correspondence with colleagues abroad upon the influence of their professional writings. By assembling a selection of key case studies, the thesis shows that sixteenth-century royal investments in scientific institutions on the Iberian Peninsula bore fruit in New Spain during the late 1500s and the 1600s as diverse communities of scientists flourished in Mexico City and its seaports. In sum, this is a study of the movement of early modern scientists, their tools and ideas as well as the concentration of these resources in the geographical and cultural surroundings of New Spain.

Acknowledgments

This thesis benefited from the expertise and generosity of many people. The Victoria University of Wellington Doctoral Scholarship, three VUW Research Travel Grants, and the Victoria Doctoral Submission Scholarship made the research for this thesis possible. My supervisors Steve Behrendt and Catherine Abou-Nemeh guided me through the process of shaping a history out of my interdisciplinary research. Lizzie Towl at the Faculty of Graduate Research has been an encouraging presence throughout, and Sydney Shep at the Wai-te-ata Press first introduced me to Print History. The staff and students of the School of History, Philosophy, Political Science and International Relations, the Early Modern Workshop, and the Postgraduate Women's Writing Group formed a vibrant community of practice. Victoria Ríos Castaño, Ruth MacEachern, and Vikki Genys read early chapters of the thesis and gave me valuable feedback. Professors Jonathan Scott (University of Auckland), Rebecca Priestley (Victoria University of Wellington), and Jorge Cañizares-Esguerra (University of Texas at Austin) offered excellent recommendations for strengthening the clarity of my argument and improving the presentation of my archival findings.

Suggestions from international scholars proved crucial to my investigation. Nora Jiménez, Pedro Rueda, Paula Findlen, Marcelo Aranda, Ken Ward, Marina Garone Gravier, Linda Arnold, Alexander Wilkinson, Robin Vose, María Portuondo, Daniela Bleichmar, Juan Pimentel, Ellen Dooley, and Joseph Clark kindly shared a bit of their vast wisdom with me. John Newsome Crossley has been especially generous in his encouragement. The "History of the Book in Hispanic-America, 16th-19th Centuries" course at the California Rare Book School (2012) provided me with a vital sense of the context for this study.

Many helpful archivists and librarians in Mexico City (Archivo General de la Nación; Fondo Reservado, Biblioteca Nacional; Biblioteca del Museo Nacional de Antropología e Historia; Biblioteca Histórica del Palacio de Minería), Puebla (Biblioteca Palafoxiana; Biblioteca Histórica Lafragua), Manila (National Library of the Philippines; Philippine National Archives; Aparicio Heritage Collection, Benavides Library UST; University of Santo Tomás Archives), Seville (Archivo General de Indias), Madrid (Sala Cervantes, Biblioteca Nacional de España; Fondos

Especiales, Biblioteca Tomás Navarro Tomás CSIC; Biblioteca Histórica de la Universidad Complutense de Madrid; Biblioteca e Archivo del Real Jardín Botánico; Biblioteca e Archivo Histórico del Museo de Ciencias Naturales; Fondo Antiguo, Biblioteca del Ministerio de Haciendas; Archivo Histórico de Protocolos de Madrid; Fondo Manuscrito, Biblioteca de la Real Academia de la Historia), Ávila (Archivo Provincial Domínicos en Ávila), and Simancas (Archivo General de Simancas) facilitated my visits to the primary sources. In particular, Diana Padilla (University of Santo Tomás Library), Glen Worthy (Stanford University Library), and Omar Escamilla (Biblioteca del Palacio de Minería) shared their enthusiasm for the seventeenth century manuscripts under their care.

Family and friends have cheered me on these last five years, and I thank them wholeheartedly. Sondra Bacharach, Michele Clark, Chiara Ferrario, Micky Vale, Louise Mataia, Corrina Connor, Hathi Pham, Ya-Wen Ho, and Lehyla Heward made writing groups productive and lots of fun. My mother, my beloved husband, and our amazing daughter have supported me from the beginning of this research journey.

Introduction

Columbus introduced European practices, and practitioners, of science to the Americas in 1492. Fast-forward forty years and the Spanish Crown had established the infrastructure that gave rise to professional communities of *científicos* in the New World.¹ While explorers relied on early modern practices of science to travel widely, map new territories, and return home alive, the first significant concentration of intellectual resources in the Americas emerged in Cortés' Mexico City. The early Habsburg kings of Spain promoted an emergent European consciousness of mathematical, cumulative, useful knowledge. They likewise supported the development of more accurate visual representations of space—cartography and hydrography.

While it may seem anachronistic to use the terms “science” and “scientist” for the historic period of this study, Spanish practitioners of early modern science often referred to themselves as *científico*, *ingeniero*, *matemático*, or by some other cognate professional identity. As recent studies of sixteenth-century Spanish science have pointed out, the development of new instruments and the use of mathematics were defining features of the Spanish approach to describing the world.² It was not the only approach—as the great ethnographic, linguistic, and natural histories of the New World illustrate—but mathematics and mechanics were, by far, the means preferred by the Crown and viceregal governments for incorporating the Americas into European frameworks of knowledge.

¹ For recent histories of the Renaissance that give an overview of Spanish imperial history see Thomas Dandeleit, "Spanish Conquest and Colonization at the Center of the Old World: The Spanish Nation in Rome," *Journal of Modern History* 69, no. 3 (1997): 479-511; Fabio López-Lázaro, "Sweet Food of Knowledge: Botany, Food, and Empire in the Early Modern Spanish Kingdoms," in *At the Table: Metaphorical and Material Cultures in Medieval and Early Modern Europe*, eds. Juliann Vitullo, et al. (Brussels: Brepols, 2007), 3-28. Also see: A. Lafuente, A. Rosal, and J. Moscoso, *Madrid, ciencia y corte* (Madrid: Consejería de Educación y Cultura, 1999); J.S. Catalá, *Ciencia y técnica en la metropolización de América* (Madrid: Doce Calles, 1994).

² María Portuondo, *Secret Science: Spanish Cosmography and the New World* (Chicago: University of Chicago Press, 2009), 3-4; Antonio Barrera-Osorio, *Experiencing Nature: The Spanish American Empire and the Early Scientific Revolution* (Austin: University of Texas Press, 2006), 7. Cañizares' work provides a broader view of the field, see Jorge Cañizares-Esguerra, *Nature, Empire, and Nation: Explorations of the History of Science in the Iberian World* (Palo Alto: Stanford University Press, 2006), 14ff.

The viceregal court of New Spain in Mexico City played a key role in supporting a scientific community.³ More than simply representing the Crown and enacting the king's wishes in the Americas, the viceroys of New Spain administered—and maintained archival documentation concerning—the Caribbean and Mesoamerica, Venezuela, the Philippines (from 1565), and what is now the Southwestern United States, including much of Florida (from 1549).⁴ Ferdinand and Isabella established the viceregal office during the fifteenth century to act as royal representatives in Naples, Sicily, and Milan. By 1535 their grandson, Charles V, had named Antonio de Mendoza the first viceroy of New Spain. Viceroys managed day-to-day financial matters and oversaw judicial processes in a microcosm of the empire.⁵ Between 1535 and 1700 there were forty viceroys of New Spain, making the average reign just over four years with two significant terms of up to fourteen years. The viceroys of New Spain financed the nautical and artillery training of much of Spanish America. They also oversaw the hydraulic engineers required for managing rainwater in the island capital, appointed cosmographers to map expanding territorial possessions, and often supported the local community of astronomers and mathematicians by, among other things, hosting visiting scientists at court. From their seat in Mexico City, the viceroys also regulated communication flows and the transport of resources from Madrid to Manila.⁶

This thesis addresses two closely-related questions: How was early modern European science applied in the Americas during the 16th-17th centuries, and what role did scientists in Spain and New Spain play in generating techniques and instruments that traveled to Europe and East Asia by the year 1700? Anglophone studies of early

³ Regarding the geopolitical centrality of New Spain, and Mexico City within it, see Boyer: "The full range of administrative functions, commercial transactions, and social intrigue centered in the viceregal capital...Located on the isthmus bridge of New Spain, Mexico City was at the center of the east-west route which joined the Atlantic and the Pacific, Europe and Asia, in a world economy; it was also the axis of the north-south route which linked the capital to the mining zone. Silver produced in the northern archipelago of mines was funneled efficiently to Mexico City where it was reinvested or spent on articles of luxury and display.... **The viceregal capital controlled the trade of the New World with the Far East and carried burdens of administration and defence.** Merchants and financiers managed an extensive commercial network which brought specie, manufactures, raw materials, and food to the city from near and far." My emphases. Richard Boyer, "Mexico in the Seventeenth Century: Transition of a Colonial Society," *Hispanic American Historical Review* 57, no. 3 (1977): 455-56.

⁴ Arndt Brendecke and Griselda Marsico, *Imperio e informacion: funciones del saber en el dominio colonial español* (Madrid: Iberoamericana, 2012), 272ff.

⁵ Manuel Rivero Rodríguez, *La edad de oro de los virreyes: El virreinato en la Monarquía Hispánica durante los siglos XVI y XVII* (Madrid: Ediciones Akal, 2011), 186.

⁶ Pedro Rueda Ramírez, *Negocio e intercambio cultural: el comercio de libros con América en la Carrera de Indias (siglo XVII)* (Madrid: CSIC, 2005), 411ff.

modern science have for the most part not focused on Spanish contributions to the history of science.⁷ However, Spanish and Mexican historians of science have produced much work on their shared transoceanic early modern period, and some notable collaborations.⁸ The question that initially spurred my research – which scientific imprints produced within the Spanish empire crossed the oceans during these years? – identified gaps in the historical record that called for a different approach to understanding the production of scientific knowledge in New Spain. My archival research for this dissertation in Mexico City, Seville, Manila, Madrid, and Simancas turned up glimpses of historical actors whose talents for the mechanical, mathematical, and natural sciences suggested potential answers to a broader set of questions.

This doctoral thesis offers a novel look at the scientific revolution from the perspective of New Spain by focusing on the circulation of new knowledge within localized as well as trans-oceanic networks of scientists and technicians. It shows how a number of figures who had been previously considered only in isolation constituted communities of scientific practitioners with active ties to the Old World. The thesis uses case studies to examine the transoceanic movement of scientists their texts and ideas; it argues for a cartographic recentering of the Spanish empire with intellectuals in Mexico City at the nexus of global networks of early modern science. Three overlapping global networks of science existed: the viceregal administration, religious orders, and commercial interests. Scientific knowledge traveled in both directions across the Atlantic through these formal and informal networks. The key figures discussed in this thesis participated through travel or correspondence in more than one set of ties, both providing local communities of science in the New World with access to tools, books, and practices generated abroad, and generating new knowledge that traveled primarily to Europe and also to parts of Asia.

⁷ For two examples of how the field has of late broadened, see Daniela Bleichmar, *Visible Empire: Botanical Expeditions and Visual Culture in the Hispanic Enlightenment* (Chicago: University of Chicago Press, 2012); Allison Bigelow, *Cultural Touchstones: Mining, Refining, and the Languages of Empire in the Early Americas* (Chapel Hill: University of North Carolina Press, [2017]). Bigelow's work highlights indigenous scientific contributions to eighteenth-century geology.

⁸ Most recently historians William Eamon, María Luisa Rodríguez-Sala, José Pardo Tomás, María Garone Gravier, Nora Jiménez, and Pedro Rueda have each participated in transatlantic scholarly collaborations which publications influenced this thesis. For a succinct overview of the debates that have plagued historians of Spanish science, "la polémica de la ciencia Española," see Portuondo, *Secret Science*, 13-16.

Five historians have influenced my research sufficiently to shift its focus from the field of Book History to the History of Science. As most scholarship on Spanish Colonial Science is published in Spanish, the three best sources for a study in early novohispanic science are the works of Elías Trabulse, María Luisa Rodríguez-Sala, and José María López Piñero. López Piñero's now classic work on the history of Spanish science *Ciencia y técnica en la sociedad española de los siglos XVI y XVII* (1979) brings together in one volume the figures and debates which shaped scientific discourse in the Spanish empire during the early modern period.⁹ Since the early 1980s, Elías Trabulse has been the authority on the colonial history of Mexican science. A founding member of the Latin American history of science community and its first dedicated journal (*Quipu: Revista Latinoamericana de Historia de las Ciencias y la Tecnología*), Trabulse produced a comprehensive anthology of scientific works printed in Mexico City and Puebla, *Historia de la ciencia en México: estudios y textos* (1983-1985). More recently María Luisa Rodríguez-Sala's studies of novohispanic scientific communities have contributed to a "networks of influence" approach to colonial science.¹⁰

There are an increasing number of studies related to Spanish-American colonial science written in English thanks to the work of Jorge Cañizares-Esguerra and others on the Intellectual History of the Spanish and Portuguese empires.¹¹ Two books in particular were foundational to this thesis: María Portuondo's *Secret Science: Spanish Cosmography and the New World* (2009) and Antonio Barrera-Osorio's *Experiencing Nature: The Spanish American Empire and the Early Scientific Revolution* (2006). Portuondo's in-depth study of cosmographers at the Casa de Contratación between 1520 and 1590 elucidates the inner workings of that most vital institution which received, filtered, stored, and produced compilations of scientific

⁹ For an anthology of primary sources for the study of science in this period see José López Piñero, Eugenio Portela Marcos, and Víctor Navarro-Brotóns, *Materiales para la historia de las ciencias en España: S. XVI-XVII* (Valencia: Pre-textos, 1976).

¹⁰ María Luisa Rodríguez-Sala, *Los cirujanos del mar en la Nueva España (1572-1820): miembros de un estamento profesional o una comunidad científica?* (México: UNAM, 2004), 172; *Letrados y técnicos de los siglos XVI y XVII: Escenarios y personajes en la construcción de la actividad científica y técnica novohispana* (México: Porrúa, 2002), 6. For viceregal networks during the eighteenth century see, Christoph Rosenmüller, "The Power of Transatlantic Ties: A Game-Theoretical Analysis of Viceregal Social Networks in Colonial Mexico, 1700-1755," *Latin American Research Review* 44, no. 2 (2009): 7-36.

¹¹ See Jorge Cañizares-Esguerra, "Iberian Science in the Renaissance: Ignored how much longer?," *Perspectives on Science* 12, no. 1 (2004); "Iberian Colonial Science," *Isis* 96, no. 1 (2005); Daniela Bleichmar, ed. *Science in the Spanish and Portuguese Empires, 1500-1800* (Palo Alto: Stanford University Press, 2009); James Delbourgo and Nicholas Dew, eds., *Science and Empire in the Atlantic World* (New York: Routledge, 2008).

data about the Americas. Barrera-Osorio's work positions the history of Spanish technologies at the forefront of the scientific revolution, and demonstrates the role of the new continents and transoceanic trade in practices of European knowledge-making. But this historiography has not yet mapped the relative significance of colonial cities for the production of early modern science.

My contribution to this body of scholarship lies in identifying Mexico City as the most significant producer of new knowledge in the Americas, before the year 1700, and as the central node within a Spanish imperial network of travelling scientists and mathematicians. Moreover I consider potential explanations for why this particular intellectual hub emerged from what some scholars regard as a decentralized empire of undifferentiated colonial locales. The factors that led to this concentration of intellectual activity in Mexico City include its: geography; population density; economic and agricultural resources; ties to the Spanish Crown's scientific expeditions; the local clustering of libraries, technical skill and intellectual expertise; and resident communities of thinkers, writers, and *científicos* who took pleasure in debating astronomical models.

Background: Spanish Science under the Habsburgs

Philip II's forebears predisposed him towards an expansionist approach in governing Spain and New Spain. His great-grandparents were none other than the Ferdinand and Isabella who funded Columbus' voyages. Their daughter and heir, Juana of Castile, married Philip Duke of Burgundy, making him Philip I of Castile in 1496 and thus uniting the kingdoms of Flanders with those of the Iberian Peninsula. The medieval Iberian Trastámara family line became Habsburg with ties in Austria for the next two centuries. Juana and Philip I's son inherited titles from both parents, including the Spanish viceroyalties of Sicily and Naples, becoming Holy Roman Emperor Charles V and Charles I of Spain until 1556. Charles married his cousin Isabel of Portugal in March of 1526, and just over a year later their son Philip II (1527-1598) was born. He inherited a vast and under-explored realm and attempted to continue to expand it, pushing into North America, the Philippines, and East Asia with mixed success.

Philip continued his father's and grandparents' support for institutions that regulated scientific observations from the New World—namely, the Casa de Contratación (House of Trade) and the Consejo de Indias (Council of the Indies).

Philip also initiated local institutions of discovery such as the Aranjuez alchemy lab and botanical gardens, the Escorial library and astronomical instrument collection, and the Academia de las Matemáticas in Madrid.¹² His architect and science advisor, Juan de Herrera, realized the king's desire to promote the mathematical sciences through Spanish-language publications and a new institution of learning.¹³ Later in life, Philip's disabling physical ailments motivated his investment in *materia medica* research, American plants for his palace botanical gardens, the distillation of plant extracts, and early support for the publication of Francisco Hernández's *Natural History of New Spain*.¹⁴ Along with his transoceanic expeditions, these projects indicate the monarch's polyfocal approach to *scientia*.¹⁵

Cartography and Spanish Science

A confluence of international events with personal interests made Philip particularly active in the scientific enterprise. In 1581 the king inherited from his mother the title of King of Portugal, which further expanded his empire. The need for reconciling the discrepancies between Portuguese and Spanish navigational maps, as well as the overall demand for mapping the empire, gave new impetus to the cartographic endeavours of the Casa de Contratación.¹⁶

¹² Much of the research on alchemy in the early modern Spanish world has situated it within Philip II's court; see the studies collected in Miguel López Pérez and Didier Kahn, eds., *Chymia: Science and Nature in Medieval and Early Modern Europe* (Newcastle: Cambridge Scholars Publishing, 2010), 138ff.

¹³ Significant archival documentation relating to Juan de Herrera's role as science advisor to Philip II has been edited by Luis Cervera Vera including: Juan de Herrera, José Simón Díaz, and Luis Cervera Vera, *Institución de la Academia Real Mathematica* (Madrid: Estudios Madrileños, 1995); Luis Cervera Vera, *Documentos biográficos de Juan de Herrera (1581-1596)* (Madrid: Academia de Bellas Artes de San Fernando, 1987).

¹⁴ Gout is thought to have been the cause of Philip II's confinement to a royal wheelchair in his later years. Henry Kamen, *Philip of Spain* (New Haven: Yale University Press, 1997), Kindle Edition Loc.6498.

¹⁵ Mar Rey Bueno, "La Mayson pour Distiller des Eaües at El Escorial: Alchemy and Medicine at the Court of Philip II, 1556–1598," *Medical History* 53, no. Supplement 29 (2009): 26-39.

¹⁶ On the occasion of the fourth centenary of Philip II's death, new research on the monarch's role in promoting science came to light. See in particular the conference proceedings in Enrique Martínez Ruiz and José López Piñero, *Felipe II, la ciencia y la técnica* (Madrid: Editorial Actas, 1999). As well as the exhibition guide: Real Jardín Botánico, *Felipe II: los ingenios y las máquinas. Ingeniería y obras públicas en la época de Felipe II* (Madrid: Sociedad Est. Conmemorativa, 1998); Jesús Bustamante García, "La empresa naturalista de Felipe II y la primera expedición científica en suelo americano: La creación del modelo expedicionario renacentista," in *Congreso Internacional "Felipe II (1598-1998), Europa dividida, la monarquía católica de Felipe II"* (Madrid: Parteluz, 1998), 39-59. A more recent contribution to studies of science in Philip's court is, Koenraad Van Cleempoel, "Philip II's Escorial and its Collection of Scientific Instruments," in *European Collections of Scientific Instruments, 1550 - 1750*, eds. Giorgio Strano, et al. (Leiden: Brill, 2009), 101-27.

Observers of the Americas recorded their findings and attempted to correct and build on the reports of other authors. Juan de la Cosa's famously early map of four-and-a-half continents—Europe, Africa, much of Asia, and eastern shore of the Americas—was a collaborative work which incorporated the exploratory cartography of Juan Rodríguez de Fonseca and others including Vicente Yáñez Pinzón, Alonso de Ojeda, Juan Vespuccio, Diego de Lepe, and Fray Andrés de Morales from whom De la Cosa took over the task of mapping the known world for Isabelle and Ferdinand circa 1500.¹⁷ The cosmógrafo-mayor at the Casa de Contratación elicited and, in turn, accumulated this data in an attempt to represent its most salient aspects on the royal nautical chart and rutter (*padrón real*).

The Consejo de Indias, a specialized appellate court that accompanied the monarch wherever he traveled, in turn regulated the physical circulation of the king's books.¹⁸ Interestingly, the Consejo sought to bypass Inquisitorial censorship (or, as was more likely, textual expurgation) by keeping certain manuscripts on "closed reserve" at the Escorial library. For example, by the late 1570s, the Consejo had deemed works written in Nahuatl politically sensitive because they described Aztec religious beliefs or practices which the Spanish Inquisition believed were threatening to the Nahua's conversion as well as to the creation of a cohesive colonial society.¹⁹ The Nahua approached codices and image-making not simply as lifeless records but rather as manifestations of the deity/animal/person represented; Nahua concepts of representation made their deities present via artistic depiction and strongly influenced their selection of media.²⁰ If, then, indigenous thought and cultural production were

¹⁷ Armando Melón, "Del portulano de Juan de la Cosa a la carta plana de Martín Fernández de Enciso," *Revista de Indias* 10 (1950): 811-26.

¹⁸ Ernst Schäfer, *El Consejo Real y Supremo de las Indias: la labor del Consejo de Indias en la administración colonial* (Madrid: Junta de Castilla y León, 2003 [1947]), 107ff.

¹⁹ Nahua religion was of primary importance in pre-contact daily life and required elaborate, often bloody, rituals to ward off devastating and unpredictable natural disasters such as earthquakes and volcanos. Book 7 of the Florentine Codex describes these rites as they related specifically to astronomical occurrences. For an anthropological discussion of Nahua rituals see Inga Clendinnen, *The Cost of Courage in Aztec Society: Essays on Mesoamerican Society and Culture* (New York: Cambridge University Press, 2010), 116ff. For a lucid study of the Pre-Columbian rites of human sacrifice and cannibalism, see Yólotl González Torres, *El sacrificio humano entre los mexicas* (México: INAH, 2006), 287ff. For an environmental history of social adaptation in the Valley of Mexico, see: G.H. Endfield, *Climate and Society in Colonial Mexico: A Study in Vulnerability* (London: Wiley-Blackwell, 2011), Chapter 2; Ross Hassig, "The Famine of One Rabbit: Ecological Causes and Social Consequences of a pre-Columbian Calamity," *Journal of Anthropological Research* 37, no. 2 (1981): 172-82.

²⁰ Recent scholarship from the Instituto Nacional de Antropología e Historia (Mexico City) on the chemical composition of Pre-Columbian pigments, posits a ritual significance of representation to Indigenous artists. See Diana Magaloni-Kerpel, *The Colors of the New World: Artists, Materials, and*

taken seriously by clerics—or understood within an early modern ethos infused with magic—books such as the Florentine Codex could be potent and threatening totems.²¹ Politically, ethnographic works were considered provocative at court because they could be used to support criticisms of Spanish colonization.²² Bartolomé de las Casas' repeated audiences with Philip II, and the royal decrees that resulted from these meetings, suggest that the indigenous population's livelihood was an ever-present concern to the monarch.²³

the Creation of the Florentine Codex (Los Angeles: Getty Research Institute, 2014), 9; "The Traces of the Creative Process: Pictorial Materials and Techniques in the Beinecke Map," in *Painting a Map of Sixteenth-Century Mexico City: Land, Writing, and Native Rule*, eds. Mary Ellen Miller, et al. (New Haven: Yale University Press, 2012), 75-91; "Real and Illusory Feathers: Pigments, Painting Techniques, and the Use of Color in Ancient Mesoamerica," *Nuevo Mundo Mundos Nuevos* (2006), <http://nuevomundo.revues.org/1462> For other case studies of how Mexica embodied their deities via representation see, Serge Gruzinski, *Man-gods in the Mexican Highlands: Indian Power and Colonial Society, 1520-1800* (Palo Alto: Stanford University Press, 1989), 31ff.

²¹ Queen Elizabeth I's advisor and astrologer, John Dee (1527–1609), famously used an Aztec obsidian scrying mirror for communicating with angels; see Glynn Parry, *The Arch Conjuror of England: John Dee* (New Haven: Yale University Press, 2013), 50ff. After 1583, John Dee also served at the court of Rudolph II (1552-1612) in Prague. The Holy Roman Emperor kept a collection of New World artifacts in his *wunderkammer* and, significantly, had, during his childhood, been tutored in Spain at the court of his uncle Philip II; see William Eamon, "The Scientific Education of a Renaissance Prince: Archduke Rudolf at the Spanish Court," in *Alchemy and Rudolf II: Searching for the Secrets of Nature in Central Europe in the 16th and 17th Centuries*, eds. Ivo Purš, et al. (Prague: Artefactum, 2017), 129-38.

²² Bartolomé de las Casas advised the Council of the Indies during the late 1550s and early 1560s; he also took an active role in prohibiting the publication of works he deemed culturally insensitive such as Oviedo's *Historia natural de las indias* (1535) wherein the author expressed a blatant disdain for native peoples. In their youth, the two Spaniards had once quarreled over a land grant and remained bitter rivals ever after planting unkind references to one another's failed endeavours in their respective chronicles; see Lewis Hanke, *Bartolomé de las Casas, Historian: An essay in Spanish Historiography* (Gainesville: University of Florida Press, 1952), 14-24. Las Casas had the king's ear in more ways than one, as Philip II's confessor, Bartolomé Carranza de Miranda, consulted with Las Casas by correspondence on matters concerning the Indies; see Antonio Fabié, *Vida y escritos de fray Bartolomé de las Casas, obispo de Chiapas* (Madrid: Ginesta, 1879), II, 591-628. One such missive regarding the term length of *encomiendas* is Bartolomé Carranza de Miranda's "Carta de Bartolomé Carranza de Miranda a Bartolomé de las Casas," (Estado, Legajo 138, fol. 360). Shortly after, Philip decreed that *encomiendas* were not heritable; they were legally dissolved upon the death of the *encomendero* although many found ways around the law or were involved in revising it locally within the colonies.

For a stirring discussion of Las Casas' role as a key witness in Spanish trials wherein 184 indigenous persons from Spanish America who had been unlawfully traded as slaves and lived on the Iberian Peninsula, sought their freedom—often successfully—under the New Laws of 1542, see Nancy Van Deusen, *Global Indios: The Indigenous Struggle for Justice in Sixteenth-Century Spain* (Durham: Duke University Press, 2015), 11ff. For case studies of Peruvian Indians who succeeded in negotiating the Spanish legal system while in Spain see, José Carlos De la Puente Luna, "Into the Heart of the Empire: Indian Journeys to the Habsburg Royal Court" (PhD Thesis, Texas Christian University, 2010), 217ff.

²³ Philip II was among those monarchs of this period whose genuine belief in the Last Judgement left visible impacts on their decrees: "The controversy over the Indians of America was a debate that embroiled all Spanish intellectuals, and Philip did not remain neutral. He (like his father) gave his continuous support to Las Casas, corresponded with him, and advanced him money." Kamen, *Philip*, Kindle Locations 860-61. Pragmatic views on this religious and legal concern for the indigenous population—as souls and subjects—highlight that the empire depended economically upon

Maps and artwork representing the New World circulated widely among scientific circles in Europe, but it took a considerable effort to keep them up to date. The most accurate of the visual representations of the Americas that crossed the Atlantic were consulted at Philip's Escorial Palace library; at least three accounts of traveling scholars—a Scottish ambassador, a German member of the Academia dei Lincei, and an unknown Spanish copyist—tell of their access to the king's collection of the latest books, maps, and images of New Spain's flora and fauna.²⁴ The Casa de Contratación (Seville) and the Casa da Indias (Lisbon) typically barred foreigners from viewing their official rutters for fear of diplomatic problems and spying. Nevertheless, during the early 1500s Italian, English, and Portuguese navigators on occasion underwent training in Seville and could have served as valuable intelligence agents. Hence, access to this new knowledge was available to those with the relevant technical or elite affiliations, and there was a range of access among the different royal institutions; records and maps produced by the Casa, where commercial interests were a concern, might be guarded, but reports and maps housed at the Escorial were accessible to travelling scholars.²⁵

Mapmakers produced geographic, hydrographic, and navigational maps. The navigational maps of the oceans, islands, rough coastlines and major ports were

the wellbeing of its native peoples; they were often farmers and labourers, without whom the empire could not produce its staple crops and its most significant exports. Hence, the natives were valuable to the Crown and viceregal government on different, and sometimes competing, levels.

When considering the colonial period, the complexity of the circumstances should not be overlooked; a powerful early modern state encountered—in new geographic settings—previously unknown civilizations and attempted to make them all participants in a single Christian-mercantilist culture. Abundant archival documentation from this period attest to a highly articulated set of legal, cultural, religious, and economic factors that contended with one another and with the immediate, local concerns of ethnically-mixed and socially diverse communities. For accounts of cultural trauma see, Miguel León-Portilla, *The Broken Spears: the Aztec Account of the Conquest of Mexico* (Boston: Beacon Press, 1962), 144.

²⁴ David Freedberg, *The Eye of the Lynx: Galileo, his Friends, and the Beginnings of Modern Natural History* (Chicago: University of Chicago Press, 2002), 246ff.

²⁵ Missionary networks were a third major avenue for tapping depictions of the Americas. While Franciscan, Augustinian, and Carmelite missions also participated in scientific endeavours, a vibrant secondary literature on the Jesuit Order's contributions to the scientific revolution has recently bloomed. See: David Buisseret, "Jesuit Cartography in Central and South America," in *Jesuit Encounters in the New World*, eds. Joseph Gagliano, et al. (Roma: Institutum Historicum S.I., 1997), 113-62; Víctor Navarro Brotóns, "Scientific Activity in Spain and the Role of the Jesuits, 1680-1767," in *Gesuiti e università in Europa, secoli XVI-XVIII*, eds. Gian Paolo Brizzi, et al. (Bologna: Clueb Editrice, 2002), 421-34; Paula Findlen, "Scientific Spectacle in Baroque Rome: Athanasius Kircher and the Roman College Museum," in *Jesuit Science and the Republic of Letters*, ed. Mordechai Feingold (Cambridge: MIT Press, 2003), 225-84; Florence Hsia, *Sojourners in a Strange Land: Jesuits and their Scientific Missions in late Imperial China* (Chicago: University of Chicago Press, 2009); Karel Davids, "In the Shadow of Jesuits: Isaac Vossius and Geography," in *Isaac Vossius (1618-1689) Between Science and Scholarship*, eds. Eric Jorink, et al. (Leiden: Brill, 2012), 189-206.

produced by mariners and consolidated into a royal rutter in Seville. Land based cartographers filled in the mountainous, urbanized, forested, swampy, or desert land masses on the maps already outlined by mariners—these were also consolidated into the *padrón real*.²⁶ The hydrographic map is a further specialization of the navigational and geographic maps which focused upon specific coasts, bays, ports, and diving or fishing areas. Bodies of water, their resources and particular relationships to land were the subjects of the hydrographic map and made them particularly useful to pearl divers and early modern excavators of sunken ships. In addition, cartographers also produced chorographic maps, urban maps which captured an inhabited area's ambiance and which, significantly, served throughout the viceregal period as evidence of an indigenous claimant's territorial possessions. When indigenous nobles or entire communities (*altepetl*) used the Spanish legal system to claim titles to land a chorographic map was often used as supporting evidence.²⁷ The legal validity of maps in court was consistent with Spanish property laws and illustrates the value of maps, as well as the role of European mapmakers or indigenous artists, both for the science and for the culture of New Spain.

Like other cartographic projects, hydrographic expeditions supported the Crown's data gathering projects and highlighted the best access to natural resources. Long before Habsburg support of science declined in Spain,²⁸ explorer-entrepreneur Nicolás de Cardona garnered royal backing from Philip III to produce a hydrographic atlas of the Pacific ports of Mexico, Baja California, and much of the California coast: *Descripción Hidrográfica y geográfica de muchas tierras del norte y del sur y de los mares de las Indias* (ca.1621).²⁹ In addition to scenic panoramas of the coastline, the

²⁶ Alison Sandman, "Spanish Nautical Cartography in the Renaissance," in *The History of Cartography*, ed. David Woodward (Chicago: University of Chicago Press, 2007), 1095-142.

²⁷ Some of the documentation on these land titles and grant requests can be found within the descriptive reports, known as *relaciones geográficas*, elicited by the Casa de Contratación for official chronicles, for the cumulative mapping of the Spanish territories, and for gathering statistical data. For representative examples of these qualitative reports, see Germán Vázquez, *Relaciones de la Nueva España* (Madrid: Historia-16, 1991), 17ff; R. Acuña, ed. *Relaciones geográficas del siglo XVI: México* (México: UNAM, 1985), 29ff. For a discussion of the indigenous art of the maps accompanying these reports see Barbara Mundy, *The Mapping of New Spain: Indigenous Cartography and the Maps of the Relaciones Geográficas* (Chicago: University of Chicago Press, 1996), 61ff.

²⁸ Royal support for science began to taper during the reign of Philip IV, "El Grande," (r. 1621-1665), and the economic crises of Charles II's "bewitched" reign (1665-1700) significantly diminished royally-funded science. However during the eighteenth century, the Bourbon monarchy reestablished royal support for large-scale scientific endeavours. See Christopher Storrs, *The Resilience of the Spanish Monarchy 1665-1700* (Oxford: Oxford University Press, 2006), 118-19.

²⁹ Elías Trabulse, *Ciencia y tecnología en el Nuevo Mundo* (México: FCE, 1994), 18-23. The standardization of shipbuilding regulations also took place during Philip III's reign.

work details new locations for harvesting pearls. Previous accounts of pearl fishing had described the best pearl fishing locations in the Atlantic, off the coast of Venezuela, and referred to indigenous as well as African diving practices; Spanish inventors had been applying to the Crown for diving and fishing tool patents since the early 1520s.³⁰ Cardona's account, however, established the best pearl fishing spots and techniques on the Pacific coast with incidental but significant references to the Jesuit missions in Baja California as well as accounts of desert landscapes and inhospitable natives.³¹ Hydrographers such as Cardona illustrate how resource extraction and trade frequently accompanied cartographic projects.³²

The Viceregal Court and Science in New Spain

Philip's proclivities made scientific ventures a frequent recipient of his royal patronage.³³ But between Columbus' voyages and the end of Philip II's reign in 1598 just over a century later, the source of funding for scientific ventures changed from the Crown in Spain to the Viceregal court in New Spain. Since the king and his successors relied upon bullion from colonial mines, the funding of Spanish science became a matter in which the viceroys of New Spain also participated.³⁴ As New

³⁰ Molly Warsh, "A Political Ecology in the Early Spanish Caribbean," *William & Mary Quarterly* 71, no. 4 (2014): 517-48. For more on the patents see, Barrera-Osorio, *Experiencing Nature*, Appendix II, 140-41.

³¹ A myth about the riches of those Baja missions in combination with the Jesuits' reputation as defiant to regional governors, particularly on the *reducciones* of the Southern Cone, led to their complete expulsion from all Spanish territories in 1776 under the Bourbon monarchs. Some of these expelled Jesuits were *criollos*, born in the Spanish overseas territories, and were nevertheless relocated to Rome or the Jesuit colleges of Austrian-Habsburg Europe. The expelled Jesuits were required to leave all their communal and personal possessions in situ; hence, inventories of their libraries and personal book collections can be found at the Archivo General de la Nación in Mexico City, and are a rich resource for the intellectual history of the colonial period in New Spain. (See Figure 5.4)

³² Trabulse, *Ciencia y tecnología*, 18.

³³ López Piñero's chapter on the demographics of Spanish science in the sixteenth and seventeenth century points out that the Kingdom of Castile had the highest concentration of resident scientists in Spain and had more than twice as many as the next highest region. From a total of 486 authors, clergymen-scientists outnumbered noblemen-scientists by a factor of two in many subfields—mathematics, cosmography, natural philosophy—but not in geography, navigation, military engineering, and medicine. Lay non-elites were more numerous in medicine and navigation. See José López Piñero, *Ciencia y técnica en la sociedad española de los siglos XVI y XVII* (Barcelona: Labor Universitaria, 1979), 66-72, Tables 8 and 9.

³⁴ After the late-1940s, economic historians relied upon "Berkeley School" Latin-Americanist Woodrow Wilson Borah's figures when discussing early colonial México: Woodrow Borah, *New Spain's Century of Depression* (Berkeley: UC Press, 1951), 18ff. Since the 1980s, however, an influential set of revisions have contested Borah's notions of a "seventeenth-century decline." Tepaske and Klein reassessed the implications of Borah's data by introducing royal treasury accounts as well as Peter Blakewell's findings on the rise in late seventeenth century mining outputs in: John TePaske and Herbert Klein, "The Seventeenth-Century Crisis in New Spain: Myth or Reality?," *Past & Present*, no. 90 (1981): 116-35. For the debate held by the journal *Past & Present* see: "A Rejoinder," *Past & Present* 97, no. 1 (1982): 156-61. Also see: Louisa Hoberman, *Mexico's Merchant Elite, 1590-1660*:

Spain's economy grew into the Crown's major source of revenue for military and defence expenditures within the empire—furnishing key ports with fortifications, construction workers, and soldiers' salaries—the viceroys also became responsible for financing royal science in the overseas territories.³⁵

By 1600 the viceregal court in Mexico City had thus become the hub of early modern science in the Americas. The patronage of science moved westward from the Iberian Peninsula to the provinces, in this particular case, the viceroyalty of New Spain. The viceroys were frequently selected from aristocrats with mathematical or astronomical training; Antonio de Mendoza is a great example of a viceroy who was also a skilled astronomer. The locus of patronage eventually became more immediate, as Philip II set a precedent of funding his expeditions to the colonies by way of the viceroyalties themselves.³⁶ As Huguette and Pierre Chaunu demonstrated through the use of shipping records at the Archivo de Indias in their pathbreaking *Seville et l'Atlantique* (1949), imperial defence contracts and *situados* (subsidies for defence) not only went to New Spain but were also funded by bullion sourced there. Hence, New Spain developed a fast-growth economy during the sixteenth-century and seventeenth-centuries which, from 1540 onward, included the expansion of European agriculture and ranching.³⁷ The viceroy of New Spain controlled the resources to pay

Silver, State, and Society (Durham: Duke University Press, 1991), 33ff. A recent trend in the historiography attributes Spain's economic instability during the second half of the seventeenth century partly to a significant emigration of labourers; migration to the Americas increased at this time for many reasons including agricultural failures in Spain. Sergio Rodríguez Lorenzo, "El mar se mueve: la experiencia del viaje trasatlántico entre los pasajeros de la Carrera de Indias (Siglos XVI, XVII)," *Communication and Culture e-journal, University of Belgrade* Special Issue 1 (2013): 67-78.

³⁵ J. Lynch, *Spain Under the Habsburgs: Spain and America, 1598-1700* (Oxford: Blackwell, 1969), 215-18. Cochineal, a prized red dye sourced from cactus insects, generated a significant source of the revenue: "It first saw export from México to Spain during the 1540s and then to the rest of Europe and Asia, becoming the second-most profitable trade item from the New World after silver." Barbara Anderson, "Evidence of Cochineal's Use in Painting," *Journal of Interdisciplinary History* 45, no. 3 (2014): 337ff. Anderson identified cochineal-pigment in woolen tapestries and well-known works of European Golden Age art as well as contemporaneous pieces produced in East Asia, and shows that New Spain was by far the greatest supplier of cochineal in the world during this period.

³⁶ The Academia de las Matemáticas in Madrid was intended specifically to train courtiers who would be sent to the overseas territories as detailed in the academy's constitution by Juan de Herrera: Herrera, Díaz, and Vera, *Institución*, 23-24.

³⁷ Lynch, *Spain*, 218. The first Atlantic shipbuilding facilities were located at Havana and San Germán (Puerto Rico). By the 1530s Hernán Cortés had established shipbuilding facilities at Veracruz (Mexico) as well, and from then on shipyards sprang up around the Caribbean including the coast of Venezuela at Araya, and later Cartagena de Indias, Colombia, as well as Portobelo in Panama. By 1630, shipyards and port fortresses appeared on the Pacific as at Acapulco (Mexico) and Manila. Also see: Woodrow Borah, *Early Colonial Trade and Navigation between Mexico and Peru* (Berkeley: UC Press, 1954), 6.

For a brief history of Spanish ranching, see Charles Bishko, "The Peninsular Background of Latin American Cattle Ranching," *Hispanic American Historical Review* 32, no. 4 (1952): 491-515. A more in-depth study of ranching in New Spain confirms Bishko's central claims, see: William

out three-quarters of the costs of the Spanish fleets on the Atlantic.³⁸ Science, industry, and entrepreneurs with technical expertise came together in the rising economy of the Americas.

Coastlines on both the Atlantic and the Pacific made New Spain *the* major player in both sets of transoceanic science economies. From forest-management and shipbuilding to astronomy-aided cartography to urban water management, the needs and opportunities for commerce relied heavily upon technical knowledge which the early modern Spanish-language publishing industry made available. From the early 1600s, Seville and later Cádiz directed the flow and production of ships. By 1640, at least forty percent of the ships documented in Spanish transoceanic trade were built in the Americas.³⁹ Shipbuilding was an art as well as a science, requiring collaboration between builders with tacit knowledge and those with explicit mathematical training to direct the production of a seaworthy vessel. Vulnerable as they were to piracy, the ports and docks of New Spain required military forts to protect their valuable haulage. Another set of engineers, builders, and armoury technicians concentrated their intellectual resources in a large community around the shipyards for the construction of forts.⁴⁰

Over the course of the seventeenth century a community of scientists in New Spain hosted a variety of international or itinerant figures and produced mathematical writings that crossed both the Atlantic and the Pacific. Some of these scientists and technicians sought to secure financial gains for their families like the viceregal armourer Cristóbal Gudiel, while others, such as the Carmelite Fray Andrés, pursued a mixed career of writing and applying mathematics to engineering and design. In either case, these figures often participated, willy-nilly, in projects that produced a significant quantity of information about the impact of early modern science upon colonial life.

Dusenberry, *The Mexican Mesta: the Administration of Ranching in Colonial Mexico* (Urbana: University of Illinois Press, 1963), 21.

³⁸ Huguette Chaunu and Pierre Chaunu, *Seville et L'Atlantique*, vol. VII (Paris: SEVPEN, 1957), VIII, I, 667.

³⁹ Lynch, *Spain*, 215. In reference to the economic performance of American ports, Lynch calls shipbuilding the "soundest growth industry in the New World" during the seventeenth century.

⁴⁰ Concerning these communities of military engineers, see: José-Antonio Calderón Quijano, "Ingenieros militares en Nueva España," *Anuario de Estudios Americanos* 6 (1949): 1-72.

Funding Science after Philip II's reign: Viceregal Necessity

After Philip II's reign, Spanish science benefitted, to some extent, from the institutions that he had established but the circumstances of later reigns and the personal proclivities of the monarchs differed markedly from his. Philip III (r.1598-1621) and Philip IV (r.1621-1665) focused upon maintaining and peopling their vast territories during the seventeenth century.⁴¹ Meanwhile the closure of the Academia de las Matemáticas in 1625, near the start of Philip IV's reign, illustrates the reduction of funding for scientific education. The locus of science education in Madrid shifted from the Plaza de Oriente at the king's front door, to a Jesuit domain at the Colegio Imperial adjacent to the Church of San Isidro. No longer would the monarch handpick his royal architect-engineers to oversee instruction at the academy as Philip II had done with Juan de Herrera and Tiburzio Spannocchi (1541-1606) at the academy's founding in 1582. The shift from a secular academy where instructors and aristocrat-students did not necessarily seek to have an affiliation with any particular religious order, to one run by a proud and politically-fraught order, would have added another degree of bureaucratic distance between royal support and scientific endeavours. The quality of instruction likely stayed the same as many of the Jesuit instructors had also taught at the academy, but the ties to the Crown would have changed. Subsequently, Queen Regent Mariana of Austria (r.1665-1677) and the wives of her "bewitched" son Charles II (r.1678-1700) ruled during a period of political and economic instability.⁴² While treatises by Spanish physicians of the exploratory *novator* group continued to grow,⁴³ royal patronage of scientific works fell by the wayside during

⁴¹ Rampant inflation in Spain during Philip IV's and Charles II's reigns compounded the damage caused by privateers and exacerbated tense foreign relations with England and the Netherlands. The Spanish Crown's purchasing power—and budget for science—during the second half of the seventeenth century was not what it had once been. By contrast the viceroyalty of New Spain, with its Pacific and Atlantic markets, did not experience the effects of European inflation in the same way and had the means to patronize scientists during this period. Tepaske and Klein consulted records of mining outputs in New Spain and found that its economy grew during these years; see TePaske and Klein, "A Rejoinder."; Herbert Klein, "The Great Shift: the rise of Mexico and the Decline of Peru in the Spanish American Colonial Empire, 1680–1809," *Journal of Iberian and Latin American Economic History* 13, no. 1 (1995): 35-61.

⁴² Charles II suffered from physical, intellectual, and psychological disabilities often attributed to multiple generations of Habsburg in-breeding. Of Charles' two wives, Marie Louise de Orléans (1662-1689) and Maria Anna of Neuburg (1667-1740), the second was a more successful politician. Storrs, *Resilience*, 157ff.

⁴³ José López Piñero, *Bibliographia medica hispanica, 1475-1950*, vol. 1 (Valencia: Universidad de Valencia, 1989); José López Piñero, Francesc Bujosa Homar, and Víctor Navarro Brotóns, *Los impresos científicos Españoles de los siglos XV y XVI: Inventario, bibliometría y thesaurus* (Valencia: Universidad de Valencia, 1986), 12.

these years.⁴⁴ As such, during the seventeenth-century science in the colonies was increasingly funded and organized by the viceregal administration. Not until the eighteenth century did the Crown again initiate large-scale scientific expeditions;⁴⁵ in the meantime colonial academics, medical practitioners, and technically-skilled entrepreneurs established a lively community of scientists in the centre of the overseas territories, Mexico City.

Spanish colonial science focused upon the application and testing of new knowledge in order to solve specific problems of transport, exchange and communication; theory-heavy natural philosophy was considered less of a necessity.⁴⁶ Indeed, Spanish explorers cited classical authors in order to explicitly correct outdated geographies and speculations about the Tropics.⁴⁷ Astronomy, botany, and hydrology explorations enjoyed royal backing as the chapters of this thesis show. The Casa de Contratación used surveys and do-it-yourself gnomon kits to crowd-source geographic data about the Americas and updated them in response to feedback from

For an in-depth discussion of the novator movement and the group's "scientific subculture" outside the royal courts see José López Piñero, *Medicina e historia natural en la sociedad española de los siglos XVI y XVII* (Valencia: Universitat de València, 2007), 323ff; Miguel López Pérez, "Novatores or Alchemists? A Spanish Historiographical Problem," in *Chymia: Science and Nature in Medieval and Early Modern Europe*, eds. Miguel López Pérez, et al. (Newcastle: Cambridge Scholars Publishing, 2010), 331-33.

⁴⁴ López Piñero, *Ciencia y técnica*, 16ff.

⁴⁵ The Spanish geographic and botanical expeditions of the late eighteenth and early nineteenth centuries are notable examples of the precedents set by Philip II's sixteenth-century expeditions. The early expeditions were regarded as models for later scientists who sought to complete and surpass Hernández's work. On a Bourbon-era geodesic expedition from the Viceroyalty of Peru see: A. Lafuente and A. Mazuecos, *Los caballeros del punto fijo: ciencia, política y aventura en la expedición geodésica hispanofrancesa al virreinato del Perú en el siglo XVIII* (Barcelona: Serbal, 1987). Daniela Bleichmar and Neil Safier have both published studies of Spanish expeditions during the eighteenth-century; also see Juan Pimentel's work on eighteenth-century Spanish palaeontologists: *El rinoceronte y el megaterio: un ensayo de morfología histórica* (Madrid: Abada Editores, 2010), and J.M. López Piñero and T.F. Glick, *El Megaterio de Bru y el presidente Jefferson. Una relación insospechada en los albores de la paleontología* (Valencia: CSIC, 1993).

⁴⁶ Maria Portuondo has brought Arias Montano and other Spanish natural philosophers of this period to light—a much needed addition to the history of science in the sixteenth-century; see María Portuondo, "America and the Hermeneutics of Nature in Renaissance Europe," in *Global Goods and the Spanish Empire, 1492–1824: Circulation, Resistance and Diversity*, eds. Bethany Aram, et al. (London: Palgrave, 2014), 82ff.

⁴⁷ Late sixteenth-century Spanish experimentalist, Diego de Santiago (1598) wrote that ancient science appeared to have been "written from speculation without being checked against demonstrations and experience... [E]ach day we uncover other findings and to those we add corrections, and in this way all things are made more perfect over time." Santiago goes on to mention the scientific instruments which he has built in order to improve his observations and how when he asked about that which he does not have experience, he refrains from offering speculations. López Piñero, *Ciencia y técnica*, 166. For a discussion of Spanish corrections of the classical authorities see, Cañizares-Esguerra, *Nature*, 14ff.

their users.⁴⁸ Rutters and other navigational maps were the result of consolidating explorer's logs and often required collaboration or teams of mapmakers. The diffusion of these data often took the form of published books about mathematics, mining, *material medica*, and astronomy.⁴⁹ When Juan de Herrera's Academia de Matemáticas in Madrid became a Jesuit institution after 1625, the mathematical focus of Spanish science continued and the networks expanded to overseas missions in the Americas and East Asia. Likewise, when Crown-initiated research expeditions became explicitly viceregal projects under Philip IV, science continued in large part through funding for defense, cartography, and water management.⁵⁰

Viceregal science made use of the institutions established by Charles V and Philip II, concentrated its resources in the capital, and included more mapping of territories. In 1535 the first Viceroy of New Spain, Antonio de Mendoza, arrived at the Palacio Virreinal (rebuilt from what was originally Cortés' home) in Mexico City, promoting the interests of early modern science. Included with his personal effects: the first astrolabe signed by Gualterius Arsenius in Louvain, Belgium.⁵¹ With it and other tools, Mendoza calculated the coordinates of Mexico City in 1536 to a high degree of accuracy. In 1535 he established the glassworks in Puebla, a culturally significant satellite city on the way to the capital from the Atlantic port at Veracruz.⁵² And in 1539 he saw the first printing press in the Americas established across the street from his residence at the Palacio Virreinal.⁵³ In 1548 he commissioned a map of

⁴⁸ Howard Cline, "The Relaciones Geográficas of the Spanish Indies, 1577-1648," in *Handbook of Middle American Indians*, ed. Howard Cline (1972), 232.

⁴⁹ See note 42. Víctor Navarro Brótons and Antonio Ibarra, *Bibliographia Physico-matemática Hispanica (1475-1990)* (Valencia: Instituto López Piñero, 1999), 34ff; José López Piñero, Luís García Ballester, and Mariano Peset Reig, *Bibliografía histórica sobre la ciencia y la técnica en España* (Valencia: CSIC, 1973), 12.

⁵⁰ Towards the end of the seventeenth century when optics and physics leapt to the foreground of early modern European science, Spanish and Spanish-colonial scientists continued to pursue their own needs and interests via cartography, astronomy, medicine, and engineering. In the late eighteenth century, the Bourbon Monarchy began to patronize major scientific expeditions to Spanish America and the Pacific, Crown-sponsored large-scale expeditions had all but disappeared after Philip III's reign (r.1598-1621).

⁵¹ Koenraad Van Cleempoel, *A Catalogue Raisonné of Scientific Instruments from the Louvain School: 1530 to 1600* (Turnhout: Brepols, 2002), 35-39; "The Migration of Instrumental Knowledge from Flanders to Spain: The Role of the Sixteenth-Century Flemish Instrument Maker Petrus ab Aggere," in *Silent Messengers: The Circulation of Material Objects of Knowledge in the Early Modern Low Countries*, eds. Sven Dupré, et al. (Berlin: Verlag, 2011), 82.

⁵² For a study of family ties in this significant satellite city see, Ida Altman, *Transatlantic Ties in the Spanish Empire: Brihuega, Spain & Puebla, Mexico, 1560-1620* (Palo Alto: Stanford University Press, 2000), 21ff.

⁵³ The first printing house established in the Americas is on Calle Moneda, just between the archeological site of the Templo Mayor and the Palacio Nacional in Mexico City. The building was constructed originally as the home of the conquistador Gerónimo de Aguilar in 1524 and repurposed

Mexico City from the *tlacuilos*, indigenous scholar-artist-scribes, of the Colegio de Tlatelolco. The mixed renaissance and indigenous perspective of the map—characteristic of much novohispanic religious art—illustrates the cultural syncretism that was underway.⁵⁴ The viceroy's decision to assign this task of cartography to the Colegio rather than to other officials in his court suggests that it was a locus of particular skills recognized by the court. It also suggests a patronage relationship that might explain the Colegio's dedication of an herbal-medical treatise known as the *Cruz-Badiano Codex* to the viceroy's son, Francisco de Mendoza in 1552.⁵⁵ Fifty years later another viceroy's adopted son, Sebastian de Vizcaíno, mapped the coast of Japan and introduced a style of European clock that the Japanese then began to manufacture.⁵⁶ Viceroys and their families played an important role in disseminating the practices of early modern science in New Spain.

Mexico City - Capital of Early Modern Science in the Americas 1570-1700

Knowledge produced in the Americas—which by the year 1700 was primarily organized, funded, or documented in Mexico City—helped to drive early modern science and the various “scientific revolutions” taking place throughout Europe. As Irving Leonard demonstrated in the 1950s, by comparing the book trade in Mexico City to Boston ca. 1680, the financial, institutional, and bibliographic resources of North America were far greater in New Spain than in the English colonies.⁵⁷ Likewise, the production of new knowledge was greater in Mexico City, a city that attracted migrant and itinerant scientists, technicians and mathematically trained

for a Cromberger printing house by Archbishop Juan de Zumárraga under the auspices of Charles V in 1539; see, Clive Griffin, *The Crombergers of Seville: The History of a Printing and Merchant Dynasty* (Oxford: Clarendon Press, 1989), 89.

⁵⁴ The map is currently held by the Library of the University of Uppsala in Sweden. Marina Garone Gravier, "Sahagún's Codex and Book Design," in *Colors between two Worlds: the Florentine Codex of Bernardino de Sahagún*, eds. Gerhard Wolf, et al. (Cambridge: Harvard University Press, 2011), 163ff.

⁵⁵ *Ibid.*, 169. For a recent orientation in Codex Badianus research see: Alejandro de Ávila, "The Codex-Cruz Badianus: Directions for Future Research," in *Flora: The Aztec Herbal*, eds. Martin Clayton, et al. (London: Brepols, 2009), 45ff.

⁵⁶ Zelia Nuttall, *The Earliest Historical Relations Between Mexico and Japan: From Original Documents Preserved in Spain and Japan* (Berkeley: The University Press, 1907), 12.

⁵⁷ The first printing press in New England can be traced to Massachusetts in 1640, and in New France to Montreal in 1776; see, Irving Leonard, *Baroque Times in Old Mexico: Seventeenth-Century Persons, Places, and Practices* (Ann Arbor: University of Michigan Press, 1960), 36 and chapter XI.

clergy.⁵⁸ It is not surprising that Mexico City, founded in 1521, has the longest history as a site of scientific knowledge production in the Americas.⁵⁹

Mexico City's location at the geographical centre of the Spanish empire made it the key location for trade between Asia and Europe. Large quantities of goods and many people of scientific import gathered there or passed through regularly. Mexico City institutions such as the university, the viceregal court, city council, the royal mint, printing houses, and private libraries as well as larger ecclesiastical libraries managed knowledge production networks with Madrid and Seville, Puebla, Peru, the Philippines, and ports like Veracruz, Acapulco, Havana and Cartagena, as well many other frontier sites and ports.

The roots of Mexico City's emergence as the central node of these networks were laid in Cortés' time. When Cortés arrived in Mexico, he leveraged the infrastructure of an existing empire. During the first few years of Spanish control of Tenochtitlan/Mexico City, Cortes' administrators accompanied the Triple Alliance tribute collectors.⁶⁰ In this process of apprenticeship Spanish officials tapped various trade routes and gauged agricultural productivity, and they identified regional, indigenous leaders for positions within a Spanish-structured government. As structures of trade, tribute, and communication were already in place, Cortés might have sought to create an independent state—not simply a viceroyalty of Spain—that controlled trade to Europe from the Pacific.⁶¹ The threat of Cortés' secession was

⁵⁸ A little-known but representative example of the missionaries to visit New Spain, Martín Ignacio de Loyola (1550-1606)—Ignatius Loyola's grandnephew—was during the 1580s one of the earliest persons to circumnavigate the globe twice, passing through Mexico City on both trips. He is known for his missionary work in China and support for the indigenous population along the Río de la Plata. The *Viaje alrededor del Mundo* (1585) is an account of his first voyage.

⁵⁹ The Archivo General de la Nación in Mexico City holds the largest single collection of historic documents in all of Latin America. Until the early nineteenth century when the current nations of Latin America declared their independence from Spain, Mexico City's then viceregal archive was a clearinghouse of document duplicates from nearly all the Spanish overseas possessions.

Mexico City's greater "social-tie density" suggested by its greater population relative to other cities in the Americas, during the sixteenth and seventeenth centuries, made it a rich location for scientific endeavour in part because of "information contagion." Arbesman, Steinberg, and Strogatz's 2009 paper on innovation and the generative complexity of social networks in urban areas has correlated larger cities with the production of significantly greater rates of what researchers define as "innovation." In 2013, another study revisited the model and posited an explanation of the phenomenon: among other characteristics, larger cities facilitate increased numbers of face-to-face contacts and the social transmission of information. See Samuel Arbesman, Jon Kleinberg, and Steven Strogatz, "Superlinear Scaling for Innovation in Cities," *Physical Review E* 79, no. 1 (2009): 016115.1; Wei Pan et al., "Urban Characteristics attributable to Density-driven Tie Formation," *Nature Communications* 4, no. June (2013): 1.

⁶⁰ Ethelia Ruiz Medrano, *Reshaping New Spain Government and Private Interests in the Colonial Bureaucracy, 1535-1550* (Boulder: University Press of Colorado, 2012), 3ff.

⁶¹ Christian Duverger, *Cortés* ([Madrid]: Taurus, 2012), Kindle location 3151.

sufficiently worrisome that Charles V designated Primera Audiencia (1527) members such as Nuño de Guzmán to compete with Cortés for land claims and eventually to drive Cortés to the royal court. While the first Audiencia did not establish enduring institutions, the Segunda Audiencia, which began in 1532, set the foundations of Spain's American empire by establishing a new set of legal procedures for hearing indigenous grievances. Mexico City would become the major urban centre of a new empire.

New Spain held a royal monopoly on the trade with East Asia via Spain's highly prosperous outpost in the Philippines, Manila Harbour, which was administered and settled as a province of New Spain beginning in the 1570s.⁶² Miguel López de Legázpi (c.1502-1572) had originally used the port in Cebu from 1565, and subsequently set up the Fort of San Pedro, but the site was vulnerable to privateers. By 1593 Manila had become the official Spanish port city, and Manila's Cavite shipyards built approximately 180 galleons during the colonial period.⁶³ The Manila Galleons were popularly known in New Spain as the "Nao de China" because the vast majority of the products had originated at the ports of Fujian, China and had been resold by Chinese traders in Manila—the Sampan Trade.⁶⁴

On the other side of the Pacific, the Acapulco-Navidad shipyards also produced, repaired and provisioned the biannual galleons for their three month trip to Manila, stocking the galleons with up to 2 million *pesos* (pieces of eight) in silver and

⁶² Why New Spain and not the Viceroyalty of Peru held a monopoly over the Manila Galleons has some likely explanations: Peru did not have a ready Atlantic port, Cartagena in the Caribbean and Buenos Aires in the Southern Cone were both difficult to access from its Pacific port at Callao because of the distance and difficult terrain which included the Andes Mountains and the Amazon River Basin; the known trade winds were located in the northern Pacific and the travel time of the journey from Manila to Acapulco was at the limits of human endurance, so extending the trip further south was not practicable; in the South Pacific tradewinds are characterized by alternating high and low pressure systems that move west to east; the overland journey from Acapulco to Veracruz was safer than the shorter overland travel across the isthmus of Panama where thick jungles, swampy terrain, and malaria made it a haven for pirates and maroon communities. Slightly more arbitrary was historical contingency: the voyages of exploration which claimed the Philippine Islands had embarked from the Pacific coast of New Spain and those original royal title grants remained in place throughout the Spanish colonial era. The monopoly appears to have been in place by the time of a real cédula dated 1582 that prohibited Peru from legally participating in the galleon trade.

⁶³ The Manila Galleons averaged a 2,000 ton cargo and 1,000 passenger capacity. Much of this discussion of the Manila-Acapulco trade is based upon: Rainer Buschmann, Edward Slack, and James Tueller, *Navigating the Spanish Lake: The Pacific in the Iberian World, 1521-1898* (Honolulu: University of Hawai'i Press, 2014), 23ff.

⁶⁴ Other East Asian traders also congregated in Manila selling products from Thailand, Vietnam, Cambodia and Portuguese Macau. The voyage to New Spain's Pacific ports took anywhere from six to nine months depending on weather conditions; the galleons sailed north towards Japan then across a vast open sea to the coast of Alta California. For nearly 250 years it was a profitable shipping route for those who managed to avoid scurvy.

New World foodstuffs.⁶⁵ Whereas in Europe gold was valued at roughly double the price of silver, in China silver sold for twice the price of gold; these two exchange rates alone produced huge profits for novohispanic traders who could sell their silver for higher prices in Asia in exchange for specialty goods and gold to Spain in exchange for European imports.⁶⁶ On the outward voyage from New Spain, Spain's Pacific shipping routes were aided by reprovisioning in Guam (the largest of the Mariana Islands, 1665-1898), and the Caroline Islands (1525-1565, 1686-1787);⁶⁷ these islands were resourced via Acapulco as well as administered as provinces of New Spain.⁶⁸ By the early seventeenth century, migration went in both directions between the Philippines and New Spain; East Asians often settled in the San Juan neighborhood of Mexico City and some Japanese settled nearer the coasts.⁶⁹

Mexico City played a pivotal role in the first global economy because of its geographical location between Europe and Asia, the Atlantic and the Pacific.⁷⁰ The

⁶⁵ On the opening of Pacific trade routes and a perception of Mexico City as the centre of the Spanish World, Elliott writes: "The conquest of the Philippines in the reign of the Philip II and their subsequent incorporation into the Mexican viceroyalty opened up trans-Pacific trading links that brought painted screens and large quantities of Chinese porcelains and silks to México and Peru. Not surprisingly, by 1600 the creole elite of New Spain were beginning to think of México as the centre of the world, facing not only across the Atlantic to Europe but also across the Pacific to the fabled lands of Asia." J.H. Elliott, *History in the Making* (New Haven: Yale University Press, 2012), 207. Scholars estimate that 650 million pesos in silver were shipped from Acapulco to Manila during the two hundred and fifty year run of the Galleon trade.

⁶⁶ Ultimately the influx of American bullion precipitated economic crises in both Europe and China during the seventeenth century. All the while Mexico City merchants were insulated from the crises by their two-ocean markets and continued to create vast wealth until the Bourbon Reforms of 1760 sought to redirect this wealth to the Spanish market. See: Dennis Flynn and Arturo Giráldez, "Born with a 'Silver Spoon': The Origin of World Trade in 1571," *Journal of World History* 6, no. 2 (1995): 202ff; José Gasch-Tomás, "Globalisation, Market Formation and Commoditisation in the Spanish Empire: Consumer Demand for Asian Goods in Mexico City and Seville, C. 1571-1630," *Journal of Iberian and Latin American Economic History* 32, no. 2 (2014): 189ff.

⁶⁷ The Spanish also held a brief settlement on the Molucca Islands from 1603 to 1663 which overlapped with Portuguese and Dutch control of the area. Spanish missionary Pedro Cubero Sebastián records his activities among the crypto-Catholic community on the islands in chapters 38-39 of *Peregrinación del Mundo* (1680).

⁶⁸ The National Library of New Zealand acquired in 2015 a Mexican imprint from 1669 written by Diego Luís de Sanvitores a Jesuit on the Marianas islands. The quarto, eighty-page book is an annual *Memorial* report on the state of the Marianas Island missions and a request for aid from the Jesuit Order in Mexico City. For a late seventeenth-century account see Gemelli Carreri's description of the Mariana Islands translated in Giovanni Gemelli Careri and I.A. Leonard, "The Pacific Crossing of Gemelli-Carreri (1697-1698)," in *Colonial Travelers in Latin America*, ed. William Bryant (Newark, Delaware: Juan de la Cuesta, 1986 [1972]), 148-50.

⁶⁹ Melba Falck Reyes and Héctor Palacios, "Los primeros japoneses en Guadalajara," *Análisis* 17, no. 50 (2014): 89-123; Edward Slack, "The Chinos in New Spain," *Journal of World History* 20, no. 1 (2009): 43. For a recent doctoral thesis on the Asian diaspora in Spanish America see Rubén Carrillo Martín, "Asians to New Spain: Asian cultural and Migratory Flows in Mexico in the early stages of "Globalization" (1565-1816)" (PhD Thesis, Universitat Oberta de Catalunya, 2015), 90ff.

⁷⁰ For an assessment of commercial risk and "free trade" in Spanish shipping towards the end of the colonial period, see: Jeremy Baskes, *Staying Afloat: Risk and Uncertainty in Spanish Atlantic World Trade, 1760-1820* (Palo Alto: Stanford University Press, 2013), 17ff.

goods carried in the Manila trade included a vast array of luxury items and contributed a major portion of Mexico City merchants' wealth.⁷¹ When these manufactures arrived in Acapulco there were celebrations, and the goods were then resold at the Acapulco Fair and either temporarily warehoused or transported overland by muletrain to Mexico City, Puebla and Veracruz.⁷² From the port of Veracruz, the East Asian goods boarded the Armada fleet, rendezvoused in Havana with the ships carrying Peruvian silver from Portobello and Cartagena, and the joint fleet sailed to Seville (Cadiz after c.1670). A significant portion of the galleon merchandise was also traded south; a Pacific coastwise sea route connected merchants in New Spain to those in the viceroyalty of Peru.⁷³

The position of Mexico City relative to the networks of trade of the Spanish empire made it a natural station for the development of scientific knowledge. Unlike the other cities in Spanish America, within thirty years Mexico City already had an array of institutional and financial resources (see Table 6.1). Cortés established the site of the royal mint (Casa de la Moneda) in Mexico City but it was not ratified by royal decree until the first viceroy, Mendoza, arrived in 1535. The mint specialized in silver pieces of eight, and during the second half of the seventeenth century gold coins were also minted there.⁷⁴ The pieces of eight, coined in Mexico, were an international currency in parts of Europe, English North America and China through the eighteenth

⁷¹ The goods included sandalwood, lacquerware, ivory, spices, porcelain, silk, cotton textiles and damask. For a study of East Asian artistic and sartorial influences in seventeenth century New Spain, see Sofía Sanabrais, "'The Spaniards of Asia': the Japanese Presence in Colonial Mexico," *Bulletin of Portuguese-Japanese Studies* 18-19, no. June-December (2009): 223ff.

⁷² Chroniclers and diarists in Mexico City, such as Chimalpahin and Gregorio de Guíjo, frequently noted the arrival of the Nao de China because it was an event of public excitement and commercial significance; church bells around the city rang to announce it. For a discussion of merchants and wholesalers in seventeenth century New Spain see, Louisa Hoberman, "Merchants in Seventeenth-Century Mexico City: A Preliminary Portrait," *The Hispanic American Historical Review* 57, no. 3 (1977): 479-503.

⁷³ A series of bays—Navidad, Acapulco, Sonsonante, Panamá, Guayaquil, Callao, La Serena, Santiago—served as harbours on the Pacific for coastwise shipping between the two viceroyalties until 1631 when trade between the viceroyalties was officially closed in order to protect the market for Spanish textiles in Peru. North-south travel overland was difficult and much less reliable along the isthmus of Panama. See, J.H. Parry, *The Age of Reconnaissance: Discovery, Exploration and Settlement, 1450-1650* (London: Orion, 2010), Chapter 12; Trabulse, *Ciencia y tecnología*, 14.

⁷⁴ In Lima, Pizarro initiated the exchange of unminted, bullion bars in 1535 contrary to Spanish law. The shortage of minted Spanish coins in Peru at this early stage of Lima's colonial era prompted petitions to the king for the establishment of a local mint. The official cédula for Lima's royal mint arrived in 1566 under Viceroy Andrés Hurtado de Mendoza. The combined Latin American silver output of approximately 150,000 tons between 1500 and 1800 along with the Manila Galleon trade created a fully connected world economy. Specie flowed into Asian and European port cities, royal courts, and banks and funded the leisure time and tools for scientific activities abroad. Dennis Flynn and Arturo Giráldez, "China and the Manila galleons," in *Japanese Industrialization and the Asian Economy*, eds. A.J.H. Latham, et al. (New York: Routledge, 2014), 71.

century. Mexican silver impacted the economies of those three regions. Mexico City's Laguna was also encircled by diverse, well-resourced, Pre-Columbian *altepetl* (city-states): Atzacapozalco, Texcoco, Tlaxcala, and Chapultepec. New Spain had a timely collection of resources and vital elements for producing new knowledge.

In comparison with other cities in Spanish America Mexico City was exceptional. Other cities were founded earlier at port sites but lacked a printing press and university or a major seat of government for decades. Whereas Mexico City had all these features within three decades of its establishment as a Spanish city, the other New World cities had a few of these components and only more slowly acquired a university and a palace courtly class to draw intellectuals together. The combination of an agreeable climate (13-18 degrees Celsius; six months a year between 17 and 18 degrees), developed agriculture, and population density of Mexico City—with its many surrounding cities dating to the Pre-Columbian period making it a local metropolitan centre—also set it apart from other Spanish American cities during the Habsburg era of colonization.

Table 0.1: Nodes in Knowledge Networks of Spanish America by 1600⁷⁵

Locations of Communication and Trade	Founding as a Spanish City	Establishment of University	Earliest Printing House	Seat of Government	Establishment of Major Port
Santo Domingo	1496	Universidad Santo Tomás de Aquino 1538	1600	--	Santo Domingo 1496
Havana	1514	Universidad de San Gerónimo de La Habana 1728	1707	--	Havana 1519 (Caribbean shipyard)

⁷⁵ The early library collections, hospitals, and court-of-appeals also contributed to the effectiveness of knowledge production in an early modern city. For Mexico City the years are: 1533 - Library of the Colegio de Tlaltelolco; 1524 - Hóspital de Jesús; 1527 - Real Audiencia. The Mexico City Council (*ayuntamiento, cabildo*) was established by 1522. Trained in law at Salamanca, Hernán Cortés was an effective administrator who valued recordkeeping; he also recognized and promoted the usefulness of adapting pre-existing Mexica systems of governance. Exceptional among the early conquistadors, Cortés established many of the components that made Mexico City a major centre within the Spanish empire. See Duverger, *Cortés*, Kindle Location 918, 4376.

Of all the regions he visited from 1799 to 1804, Alexander von Humboldt regarded Mexico City, Guatemala City, Puerto Rico, and Havana's respective cartographic collections as the most valuable and useful for his expedition. He attributed the superiority of their collection of maps and demonstrated cartographic skills to their longstanding participation in transoceanic trade. According to Humboldt, Mexico City had the largest documentary and cartographic collections in Spanish America. See Trabulse, *Ciencia y tecnología*, 34-35.

San Juan (Puerto Rico)	1521	Colegio Asilo de S. Ildefonso 1860	1806	--	San Juan 1521
Mexico City	1521	Universidad de México 1551	1539	1521 Vice-royalty of New Spain	Veracruz 1523 (Atlantic shipyard) Navidad 1531/ Acapulco 1565 (Pacific shipyard)
Lima	1535	Universidad Mayor de San Marcos 1551	1581	1542 Vice-royalty of Peru	Callao 1537
Asunción	1537/1541	Universidad Nacional de Córdoba 1613 (in Argentina)	1700	--	Buenos Aires 1580
Bogotá	1540	Universidad Santo Tomás 1580	c.1770	1717 Kingdom of Nueva Granada	Cartagena c.1600 Nombre de Dios / Portobello 1510/1597
Quito	1540 / 1556	Universidad de San Fulgencio 1586	c.1750	--	Guayaquil 1547 (Pacific shipyard)
Santiago de Chile	1540 / 1560	Universidad de San Felipe 1738	c.1760	c.1730 Capitanía General de Chile	Valparaíso 1544
Caracas	1565	Universidad de Caracas 1721	1808	--	La Guaira 1577
Buenos Aires	1580	Universidad de Buenos Aires 1821	1780	--	Buenos Aires 1580

The acquisition of the New World presented significant challenges for Europe's aspiring colonial empires. For the first time since Late Antiquity, Europeans were faced with the logistics of empire, and Spain saw itself as continuing the tradition of the Romans.⁷⁶ During the second half of the sixteenth century, Philip II's rule supported and promoted the expansion of efforts to solve the daily problems of charting, mapping, governing, and mining the new territories. Effective communication and swift transport of people, supplies, resources, and texts across

⁷⁶ For recent discussions of Spanish colonization as a dissemination of Classical Antiquity and the Latin language, see David Lupher, *Romans in a New World: Classical Models in Sixteenth-century Spanish America* (Ann Arbor: University of Michigan Press, 2006), 8ff.

vast distances required administrators to devise large scale and mathematized solutions for these difficulties. These same concerns became significant a century later for the overseas empires of the Dutch, English, and increasingly the French under Louis XIV. Spain's attempts at solving these problems were a model to be improved upon. As we can see from colonial documents during the sixteenth and seventeenth centuries, Spanish inventors submitted large numbers of applications for the equivalent of a patent on their new designs.⁷⁷

Guide to the Chapters

The first two chapters of this thesis discuss two royally-backed expeditions. The first, led by Francisco Hernández, was concerned with natural history and the other, led by Jaime Juan, with astronomy. Francisco Hernández's expedition attempted to identify the most effective medicinal plants in New Spain. It included a cartographer, Francisco Domínguez y Ocampo, and native artists. Philip II and Hernández had a clear plan for gathering *materia medica* as well as information about how to use it. What they did not know was how many new specimens Hernández would find; the wealth of material repeatedly delayed completion of the work. The naturalist spent enough time learning from mission gardeners and native herbalists to conceive of these medicinal plants and remedies using indigenous terms which his European readers later trimmed and reorganized for ease of use. The second chapter examines the extant archival documents from Jaime Juan's expedition to update the longitude and latitude figures for the ports and major cities of New Spain, including the Philippine Islands. Hernández's cartographer Domínguez y Ocampo, briefly discussed in Chapter 1, reappears here as support staff for astronomer Juan. Juan's observations of the lunar eclipse of 1584 were included among the Casa de la Contratación's figures for a revised map of the Spanish territories.

Chapters 3 and 4 examine a number of scientists and their tools in the colonies.

Chapter three introduces the hydraulic engineers of Mexico City and situates local and global knowledge on an island city whose canals and surrounding lakes made it perennially vulnerable to the rainy season. Chapter four presents the major works, ideas, and figures involved with disseminating astronomical thought in New Spain

⁷⁷ Barrera-Orsorio, *Experiencing Nature*, 140-46.

and further afield. The chapter contrasts naked-eye astronomical observations with the later use of telescopes in social spaces and discusses the local production of these scientific instruments. It examines the *tertulia* culture of science in Mexico City: novohispanic communities of science emerged by way of the viceregal court and university, as well as through long distance and transoceanic epistolary exchanges. Francisco Ximénez was an elusive figure who participated in both of these sets of scientific social ties in Mexico City and Puebla de los Ángeles. Fray Diego Rodríguez is thought to have used some of the first telescopes in Mexico City during the mid-seventeenth century, and his mathematical approach to astronomy was continued by Sigüenza y Góngora. Sigüenza y Góngora, the son of a mathematics tutor to the royal family, became an outspoken critic of astrological uses for celestial observation. The chapter addresses Sigüenza y Góngora's role in denying the celestial influence of comets on human affairs and his part in a polemic concerning the Great Comet of 1680/1681. It also tells the stories of a number of scientists who produced astronomical observations in Spanish America during this period.

The final chapter is a large-scale view of Spanish scientific publishing and print diffusion. Chapter 5 looks at the history of printing in the New World from 1539 to 1700 and the associated transatlantic book trade. The Inquisition played a role in censoring works deemed provocative or those holding "occult" status but for the most part left mathematical treatises untouched. The chapter addresses specific quantitative questions: how many of the scientific works printed in Mexico City were reprints? How many scientific texts were expurgated by the Mexican Inquisition during these years? How many works/titles of early modern science imported from Europe were present in the extant book inventories? It also examines the role of Spanish and Spanish Colonial Science within the larger sphere of European discourse about science. It makes use of late seventeenth century book reviews and unsanctioned intelligence reports to determine the extent to which new scientific knowledge produced in New Spain was disseminated across the Atlantic.

As Spain's economy underwent a recession and bullion flows slowed, the viceroys in Mexico City benefitted financially from its central position between the supply and demand of the Asian and European markets. Transatlantic science, then, was an international scene, and the viceroyalty of New Spain provided a necessary destination for the early modern scientist who travelled globally.

A number of historical figures discussed in this thesis comprised an intellectual community that has not hitherto been examined. Some like the cartographer Francisco Domínguez will illuminate the story of New Spain's role as a transmitter of data about Asia to Europe. Other better known figures such as the Dutch engineer Adrian Boot and novohispanic astronomer Sigüenza y Góngora feature in new ways, playing the role of participants in professional disputes over what constituted the best practices of particular scientific endeavours. These communities of expertise situated themselves in resource-rich port and capital cities, not as isolated fortresses but, as nodes within overlapping networks that reached all corners of the Spanish Empire.

Chapter 1 A Rare Manuscript in the Age of Print: Francisco Hernández's *Natural History of the Plants of New Spain* (1576)

*"These books of ours on The History of Plants contain nothing which has not been seen with our own eyes and tested by the senses of myself or my assistants."*¹

That any of the *Natural History of the Plants of New Spain* survived the sixteenth century seems a surprise. The years between its author's return to Madrid from New Spain and the first unabridged impression of the work included a dissatisfied royal patron, a failed print run, unofficial excerpts by other botanists, a catastrophic fire, and, finally, oblivion. The vicissitudes undergone by Francisco Hernández's original twenty-two manuscript volumes eventually whittled his magnum opus down to the six extant volumes,² in addition to the selections printed in seventeenth-century botanical works throughout Europe and the Spanish colonies.³ Hernández's recorded experiences as a witness to the lifeways and natural resources of an indigenous culture just as it was being devastated by an epidemic (*cocoliztli*) in

¹ "Letter to Philip II, 18 February 1574" transcribed in: Agustín Barreira "Los trabajos inéditos del Dr. Francisco Hernández sobre la gea y la fauna mejicanas" *Asociación española para el progreso de las ciencias* 283, 1929.

² In 1790 the botanist, Casimiro Gómez de Ortega (1740 -1818), rediscovered, at the royal Jesuit college of Mathematics in Madrid, the Hernández manuscripts which are now kept at Biblioteca Nacional and the Ministerio de Haciendas. Authorial proofreading marks indicate that the manuscripts are the *bosquejos*, drafts, which Hernández mentions in his letters. Hernández had sent Philip II a final draft of the manuscripts which were lost in the Escorial fire of 1667. Gómez de Ortega prepared a new edition for publication based upon the rediscovered rough-draft manuscripts and was inspired by them to establish the Royal Botanical Garden of Madrid's mission to house and research plants from Latin America. He was also elected a Fellow of the Royal Society of London in 1777 and opened avenues of communication between English and Spanish scientists during the eighteenth century.

³ I am borrowing a designation from the early twentieth-century historian of Iberian *materia medica*, Humberto Julio Paoli, whose syntheses of archival documents regarding Hernández's life have become influential. See Humberto Julio Paoli, "Vicisitudes de las obras de Francisco Hernández," *Archeion* 22, no. 2 (1940): 154-70. The earliest publication of many of the original documents was undertaken during the nineteenth century by the Real Academia de la Historia series *Coleccion de Documentos Inéditos para la Historia de España*, in part as a way of responding to the Wars of Independence in Latin America and the loss of Spanish colonial possessions. Publishing archival materials from the colonial period, it was hoped, would demonstrate that the new Latin American republics had sought independence for reasons unrelated to the preceding two-and-a-half centuries of Spanish imperialism. During the early twentieth century, scholars like Paoli and Barreiro published their own careful transcriptions of the Hernández archival documents. See: P. Barreiro, "El Testamento del doctor Francisco Hernández," *Boletín de la Real Academia de la Historia* 94 (1929): 475-97.

1576 demonstrate the precarious nature, and relatively untapped value, of the early modern botanical compendium.⁴

The tale of Francisco Hernández's manuscripts illustrates the obstacles to transporting and diffusing accurate information based on first-hand experience and indigenous knowledge across the ocean during the age of print. There was a fundamental incommensurability between the form that Hernández's writing took and the practical guide to medicinal plants which Philip II had commissioned. The difference between the one and the other contributed to a delayed and piecemeal publication of Hernández's works despite his conscientious approach to the investigation and his prolific production of texts.⁵ The partial diffusion of his writings into the print medium by way of the Accademia dei Lincei in Rome and the works of other botanists internationally illustrate that scientific knowledge travelled from the Americas to Europe and back again from very early on. Indeed, as this dissertation argues, New Spain was an important site for the production of scientific knowledge during the early modern period.

In disseminating his *Natural History of New Spain* Hernández employed at least three different types of intellectual networks across Europe even during the precarious manuscript stage of the work: Philip II's court in Spain, the Republic of Letters across Europe, and the missionary orders in the Americas and East Asia. The earliest reception of Hernández's writings takes place primarily within the realms of Philip II—Mexico City, Seville, Madrid, Rome, and Naples—but the intellectual network continued to expand long after the royal patron's death. Scholars were anxious to read and share news about Hernández's natural history by way of informal correspondence, particularly among well-known scientists such as those associated

⁴ The *cocoliztli* epidemic was likely an endemic disease which emerged from local rodents and affected the most vulnerable members of early colonial society. For a summary of the historical debates, see John Marr and James Kiracofe, "Was the *Huey Cocoliztli* a Haemorrhagic Fever?," *Medical History* 44, no. 3 (2000): 343ff. Outbreaks of *cocoliztli* followed periodic droughts in the Americas—tree ring analyses show drought conditions for the years immediately before and during the outbreak—and were a form of viral hemorrhagic fever spread by the vesper mouse. The illness killed natives and Europeans alike within a week of exposure. Major outbreaks took place in 1545 and 1576; Hernández witnessed the latter. See: Rodolfo Acuña-Soto et al., "Megadrought and Megadeath in 16th Century Mexico," *Emerging Infectious Diseases* 8, no. 4 (2002): 360-62.

⁵ The most complete impressions of the *Natural History* were Antonio Recchi's (Rome, 1648/50), as well as Francisco Ximénez's (Mexico City, 1615), and finally a faithful printing in Madrid based entirely upon the remaining manuscripts in 1790.

with the Accademia dei Lincei in Rome.⁶ News of the work traveled through a network of European botanists.

Despite the international attention of botanists, early in the pre-print dissemination of Hernández's findings, as in a "game of telephone" where errors in transmission are inevitable, the precise backstory of the manuscripts became at times muddled. The link between author and text became further obscured by the many editorial hands that finally published it in the mid-seventeenth century.⁷ This chapter teases out what Hernández envisioned for his voluminous manuscripts—and how his early communities of readers made use of them—by consulting Hernández's will, his remaining manuscripts, the major printed editions of his works, and early correspondence by the members of the Accademia dei Lincei who published the *Natural History of New Spain* in a series of editions between 1628 and 1651.

Among contemporary scholars of early modern botany and *materia medica*, Francisco Hernández's expedition in New Spain is well-known; although Hernández had remained somewhat forgotten until the mid-1990s when Simon Varey, Rafael Chabrán, José López Piñero, and José Pardo Tomás published their studies of the botanist.⁸ The neglect was in part due to the unacknowledged incorporation of Hernández's findings into the works of other early modern European botanists; the protracted journey of his writings into print and intellectual customs of the early modern period had made correct attributions difficult. Varey and others have defined the main contours of the historical narrative on Hernández's expedition and studies by Raquel Álvarez-Peláez and David Freedberg have highlighted the reception of his work among members of the Accademia dei Lincei. I am examining the expedition

⁶ Cassiano dal Pozzo accompanying Cardinal Barberini at the Escorial Library (Spain) on 28 June 1626 wrote: "I made certain that the first books they showed us were from that famous collection of plants and other things from the Indies... that Cesi had recommended... There were sixteen volumes in a folio size larger than the ordinary, but not quite as large as the 'royal' folio, bound in sheepskin covers stamped with gold with the King's royal arms... You would not believe the beauty and exactitude of the colours with which the figures are painted." From 'Memorias' ms. Barberini Lat. 5689 fol. 104v. Cited in *Cartas Inéditas del Humanista Escocés David Colville* Boletín de la Real Academia de la Historia, CLXX n.1, 1973, 101.

⁷ Paoli makes an assessment of the Accademia dei Lincei editions of Hernández's work and the roles of the numerous figures that brought it to print.

⁸ José López Piñero and José Pardo Tomás, *La influencia de Francisco Hernández (1512-1587) en la constitución de la botánica y la materia médica modernas* (Valencia: CSIC, 1996); José López Piñero and María Luz López Terrada, *La influencia española en la introducción en Europa de las plantas americanas, 1463-1623* (Valencia: Instituto de Estudios Documentales e Históricos sobre la Ciencia. Universitat de València-C.S.I.C., 1997); Simon Varey and Rafael Chabrán, "Medical Natural History in the Renaissance: The Strange Case of Francisco Hernández," *Huntington Library Quarterly* 57, no. 2 (1994); Francisco Hernández and Simon Varey, *The Mexican Treasury: The Writings of Dr. Francisco Hernández*, trans. Rafael Chabrán (Stanford: Stanford University Press, 2000).

and writings from the perspective of the transoceanic movement of books, people, and ideas within early modern science. This chapter examines the reception of Hernández's work to find that its reemergence during the eighteenth century spurred Enlightenment era naturalists to explore Peru and the Pacific. It also asks new questions. What was the nature of Hernandez's interactions with his indigenous guides? How was Pre-Columbian knowledge received by European scholars?

Francisco Hernández's Royal Commission

Francisco Hernández (c.1514 - 1587) was born in Montalbán near Toledo, studied medicine and anatomy at the Universidad de Alcalá, and did botanical fieldwork near Seville where he would have had his first exposure to American *materia medica*. He was employed at the Royal Monastery of Guadalupe in Extremadura as a medical botanist and translated much of Pliny the Elder's *Naturalis Historia* into Castilian, which gained him the attention of the monarch. His friendship with the king's royal librarian, philologist, and Erasmian humanist, Benito Arias Montano, in addition to his reputation as a scholar and herbalist, had brought him to Philip II's court.⁹

In Madrid, 1569, Philip II appointed Francisco Hernández as 'Protomédico de las Indias', or head of the yet-to-be-created medical board in the overseas territories.

⁹ Hernández's friendship with Arias Montano—whom Philip II assigned to oversee the publication of the famed polyglot Bible printed by the Plantin Press in Antwerp 1568-1572—has contributed to an intriguing set of arguments about the role of Erasmian Humanism in New Spain during the sixteenth century. Historian Elías Trabulse posits that Montano's association with Christopher Plantin's *Familia Caritatis* group illustrates the extent to which Montano, as well as his Spanish intellectual circle, embraced Erasmian humanism. As a participant in Montano's social circle, Hernández was in turn conversant with the humanist network of Mexico City which included Bishop Zumárraga and other reformers such as Tomás López Medel, Fray Alonso Cabello, Pedro Moya de Contreras, and Maturino Gilberti (1507-1585). Some members of this intellectual circle held posts within the Inquisition of Mexico City; see, Silvio Zavala, "El oidor Tomás López y su visión erasmista de la evangelización del Nuevo Mundo," *Memoria de El Colegio Nacional* VIII, no. 1 (1973/6): 13-45; José Miranda, *El erasmista mexicano: Fray Alonso Cabello* (México: UNAM, 1958), 5ff. Zumárraga paid tribute to Erasmus in his *Doctrina breve* c.1543 and in his *Doctrina cristiana* (1546) to Constantino Ponce. See: José Almoína, *Rumbos heterodoxos en México* (Ciudad Trujillo: Universidad de Santo Domingo, 1947), 180-85.

From 1533 to 1564 shipping records and library inventories indicate that works by Erasmus and those of his Spanish follower, Constantino Ponce de la Fuente (1502-1560), were in circulation in Mexico City; see, Luis González Obregón, *Libros y libreros en el siglo XVI* (México: Secretaria de Relaciones Exteriores, 1914), 333-47, 473-95. Some of the most popular humanist book titles in novohispanic libraries included: *Paráfrasis del Evangelio de San Lucas*. In Hernández's manuscript *Método Cristiano* (c. 1575)—a theological work aimed not at neophyte catechumens as the title might suggest but at a more particular readership—we see the exertions of Hernández's poetic ambition; the *Método* is composed in Latin hexameter, the standard meter for classical epics—fitting for a person of grand undertakings. See Elías Trabulse, "Un científico erasmista," in *Crítica y heterodoxia: Ensayos de historia mexicana* (Guadalajara: Universidad de Guadalajara, 1991), 74-77, 86ff.

As such, Hernández was required to compile information about medicinal plants for an “historia de las cosas naturales”.¹⁰ His book would be one of a series of natural histories or *materia medica* produced in this time (see Table 1.1). Unfortunately for the protomédico, the monarch had different expectations for the “historia”. Philip sought a tried-and-tested pocket guide to American *materia medica* that might hold the keys to alleviating his gout and other immediate health problems within the royal court, whereas Hernández was writing a new classic—greater in scale than those by ancient authorities of the Mediterranean—for the future.¹¹

Table 1.1: Major Sixteenth-century Authors of American Natural Histories¹²

Gonzalo Fernández de Oviedo (1478-1557) royal functionary, chronicler	<i>Sumario de la Natural Historia de las Indias</i> (1526)	Chapter LXII describes the flora of Hispaniola and Santo Domingo
Toribio de Benaente Motolinía (1482–1568) Franciscan missionary, chronicler	<i>Historia de los Indios de la Nueva España</i> (1541)	Third Treatise: chapters V, IX, XIX about flora in the Valley of Mexico
Martín de la Cruz (c. 1480-unknown) indigenous botanist physician (tlatimini ¹³) &	<i>Libellus de Medicinalibus Indorum Herbis</i> (ca.	Details indigenous materia medica in

¹⁰ Códice inédito Real Academia de la Historia, Signatura D95 *Colección de documentos ineditos* segunda serie tomo XV, 279 Consejo de Indias Madrid 1924. The institutionalization of the Protomedicato, by the viceroy of New Spain, took place in 1603.

¹¹ The Archivo de Simancas has scores of documents relating to Philip II’s royal doctors; he employed over a dozen at any given time. The royal family had many more. The Escorial palace where the king spent his later years was equipped with eleven alchemical laboratories furnished with ovens and specialized glassware. For research on the distillation of plants at Philip II’s palace and botanic gardens at Aranjuez see, Mar Rey Bueno and María Alegre Pérez, “Renovación de la terapéutica real: los destiladores de su majestad, maestros simplicistas y médicos herbolarios de Felipe II,” *Asclepio* 53, no. 1 (2001): 27-56. For a comparison of Spanish and Novohispanic pharmacy see Paula De Vos, “The Art of Pharmacy in Seventeenth- and Eighteenth-century Mexico” (PhD Thesis, UC Berkeley, 2002), 118-25.

¹² Other contemporary publications such as Valadés’ *Rhetorica Christiana* (1579) included notable illustrations and descriptions of local flora and fauna. The audience for such works consisted mainly of clergymen and missionaries in anticipation of travel to New Spain or upon their arrival. See Lina Bolzoni, “Mexican Nature in Diego Valadés’ *Rhetorica Christiana* (1579),” *Studies in the History of Art* 69 (2008): 126-41; José Pardo-Tomás, “Making Natural History in New Spain, 1525–1590,” in *The Globalization of Knowledge in the Iberian Colonial World*, ed. Helge Wendt (Berlin: Max Planck Institute, 2016), 29-48. Indigenous codices, such as the sixteenth-century Codex Tudela, also include depictions of flora used for ceremonial purposes. Medicinal plants and herbal knowledge doubled as visual art in the monastic murals of Malinalco, see Carmen Zepeda and Laura White, “Herbolaria y pintura mural: plantas medicinales en los murales del convento del Divino Salvador de Malinalco, Estado de México,” *Polibotánica*, no. 25 (2008): 173-99.

Juan Badiano (1484-1560) indigenous Latinist, scribe- translator ¹⁴	1552) Also known as the Cruz-Badiano Codex or previously as the Codex Barberini (Lat. Vat. 241)	the Valley of Mexico
Nicolás Monardes (1508-1588) Spanish physician, botanist	<i>Historia medicinal de las cosas que se traen de nuestras Indias Occidentales</i> (1565) ¹⁵	About Seville arrivals of materia medica from the Spanish Americas
Diego de Landa (1524-1579) Franciscan Bishop of Yucatán, chronicler	<i>Relación de las cosas de Yucatán</i> (1566)	Chapter XLIX about flora and fauna of the Yucatán Peninsula
Bernardino de Sahagún (1499- 1590) Franciscan ethnographer, linguist	<i>Historia general de las cosas de Nueva España</i> (1585)	Books X and XI on the Nahua materia medica of New Spain
Juan de Acosta (1539-1600) Jesuit naturalist, missionary	<i>Historia natural y moral de las Indias: en que se tratan las cosas notables del cielo y elementos, metales, plantas, y</i>	Book IV gives an account of Peruvian flora and to a lesser extent that of New Spain

¹³ *Tlamatini* literally translates as “one who knows.” León-Portilla gives examples of its use for referring to physicians and wisemen in Nahua texts. See, Miguel León-Portilla, *Aztec Thought and Culture* trans. Jack Davis (Norman: University of Oklahoma Press, 1970), 27.

¹⁴ In addition to the trilingual indigenous scribes who translated between Latin, Spanish, and Nahuatl at the Colegio de Santiago Tlatelolco, bilingual mestizo functionaries and governors participated in the production of natural histories as well. Diego Muñoz Camargo (1529-1599) and Juan Bautista de Pomar (1535– after 1601) were sixteenth-century *mestizo*—child of an indigenous and a Spanish parent—authors who included descriptions of medicinal plants and fruits in their documentary writings on Tlaxcala and Texcoco, respectively. Pomar descended from the noble line of Netzahualcoyotl; likewise the *tlacuilo* (scribe-artists) of the Colegio de Tlatelolco pertained to the pre-conquest Nahua aristocracy. On the intermediary role these figures played, see Manuel Aguilar-Moreno, “The ‘Indio Latino’ as a cultural mediator in the colonial society,” *Estudios de Cultura Nahuatl*, no. 33 (2002): 149-84. For a comprehensive account of indigenous participants in the production of early colonial books as sages, scribes, translators, and typographers, see Marina Garone Gravier, “Calígrafos y tipógrafos indígenas en la Nueva España,” *Revista general de información y documentación* 23, no. 2 (2013): 315-32.

¹⁵ During these years, Spanish-trained Portuguese physician García de Orta (1501-1568) published an influential collection of simples that he observed in India as *Colóquios dos simples e drogas he cousas medicinais da Índia* (Goa, 1563). The work circulated among European naturalists soon afterwards; Monardes and Clusius both referenced *Colóquios* in their own botanical compendia. De Orta’s stance on direct observation is typical of his milieu; like Hernández a decade later, he studied at Alcalá and had ties to the University of Salamanca: “[F]or me the testimony of an eye-witness is worth more than that of all the physicians and all the fathers of medicine who wrote on false information.” García de Orta, *Colloquies on the Simples & Drugs of India* (London: Sotheman, 1913), 274.

	<i>animales dellas y los ritos, y ceremonias, leyes y gobierno, y guerras de los indios</i> (1590)	
Juan de Cárdenas (1563-1609) Spanish migrant to New Spain who earned a higher degree at the Universidad Real y Pontificia de México	<i>Primera parte de los problemas y secretos maravillosos de las Indias</i> (1591)	Book II, chapters 7-14 describe the health benefits of Mesoamerican foods
Agustín Farfán (c.1534-1604) Augustinian physician	<i>Tractado breve de medicina y de todas las enfermedades</i> (1592)	Includes medicinal uses of plants available in New Spain
Juan de Barrios (1562-1645) Spanish physician who resided in Mexico City from 1589 to c.1638 and returned to Spain	<i>Verdadera medicina, cirugía y astrología, en tres libros dividida</i> (1607)	Acknowledges and reproduces a selection from Francisco Hernández's work.
Juan de Torquemada (c.1562-1624) Franciscan historian	<i>Los veinte yvn libros rituales i Monarchia Indiana, con el origen y guerras de los Indios Occidentales, de sus poblazones, descubrimientos, conquista, conversión y otras cosas maravillosas de la mesma tierra</i> (before 1615)	Book II, chapter 14 concerns the indigenous ceremonial uses of plants in the Valley of Mexico

As an experienced botanist and Pliny scholar, Francisco Hernández understood the potential value to medicine of the botanical information that he was to gather and make available to a wider readership.¹⁶ Indeed, while conducting his

¹⁶ “Along with my natural history [in Latin], I plan also to take, to Spain, a translation into Nahuatl **for the benefit of the natives** and a translation into Spanish for those who prefer to read in that language rather than Latin.” Hernández likely left the Nahuatl text in Mexico City but did take potted plants and medicines from New Spain so that Philip would benefit from his work immediately. Francisco Hernández, “Cartas escritas a Felipe II por su médico el Doctor Francisco Hernández desde la ciudad de Méjico por los años de 1572 a 1576 sobre la historia natural de Indias...” in *Colección de documentos inéditos para la historia de España*, ed. José León Rayón (Madrid: Viuda de Calero, 1842), 370-72; 10 Feb 1576.

fieldwork Hernández carried his own translation of Pliny's *Historia Naturalis*.¹⁷ Hernández had imbibed an appreciation for Pliny at university during his general medical training, as his professors were among those Spanish Humanists who had translated sections of Pliny's works into Spanish.¹⁸ But the conflict between the King's view of the project and Hernández's view is apparent in their letters and suggested by the drawn-out process of bringing the work to print.

The monarch requested that Hernández gather data and samples, as systematically as possible, of the medicinal plants of New Spain and of any other interesting natural resources he might encounter. After completing his fieldwork in New Spain he was to repeat the process in Peru. The king's desire for verifiable, recorded, and publishable new botanical data with its pharmaceutical applications is quite clear. Philip's instructions demonstrated that he was interested in more than received wisdom or folklore. Perhaps the king had in mind Gonzalo Fernández de Oviedo's (1478–1557) argument in the *Historia General y Natural de las Indias* (1535) about the risks of faulty plant identifications and an inconsistent nomenclature for American flora: "This disputation is for physicians: while they may want to call the *hobo* a *mirabolano*, it is not...nor other names they give it since, in these matters of medicine all kinds of oversights and worse [take place]..."¹⁹ In addition to stating that an artist and a geographer collaborate with Hernández upon his arrival in New Spain, to render the appearance and location of the plants visually, Philip requested that Hernández "experience" the medicinal effects of the plants physically, and that he describe each species in specific, concrete terms to aid others in their proper identification. The king's instructions read:

¹⁷ On the 22nd of October, 1575 Hernández sent his tenth status report about his book to Phillip II in which he reminds the monarch of his Pliny translation and commentary. This was the first full translation into Spanish of Pliny's three dozen books on plants, animals, and minerals but remained unprinted until 1970 when it was published as part of the *Obras Completas de Francisco Hernández* (ed. Somolinos).

¹⁸ Germán Somolinos D'Ardois, *Vida y obra de Francisco Hernández* (México: UNAM, 1960), Vol.3-4, Introducción. The Universidad Nacional Autónoma de México (UNAM) has recently, in mid-2015, made a new digital edition of Francisco Hernández's writings freely available online. <http://www.franciscohernandez.unam.mx/home.html>

¹⁹ Oviedo's full comment reflects a general lack of confidence in physicians' familiarity with their remedies. He sees doctors as being potentially confused when assigning curatives as he adheres to his own identification of a plum-like fruit from Hispaniola as an *hobo* rather than a similar looking fruit from India known in Europe since the Middle Ages: "It is neither a 'mirabolano' nor a species thereof. Moreover I disagree with doctors' naming them so when they are not; this would not be the worst danger that comes from Medicine nor the last falsehood that doctors engage in... and the harm is always to other peoples' lives." Gonzalo Fernández de Oviedo y Valdés, *Historia general y natural de las Indias*, ed. Juan Pérez de Tudela (Madrid: Ediciones Atlas, 1959), Primera Parte, Libro IX, Capítulo II, 250.

You shall consult all doctors, medicine men, herbalists, Indians, and other persons with knowledge in such matters, if it seems to you that they have understanding and knowledge, and thus you shall gather information generally about herbs, trees, and medicinal plants in whichever province you are... Furthermore, you are to find out how the above-mentioned things are applied, their powers, and in what quantities the said medicines are given.²⁰

The letter of appointment also includes among his duties: to describe the specifics of cultivating the plants, such as identifying in which soils they grow best; to identify the natural environment and habitats; to describe the different varieties of each that might exist; and most importantly, Hernández is to experience “first-hand” all of the above and send the unique and noteworthy medicines and herbs to Madrid in barrels or crates.²¹

With the monastic austerity for which Philip II later became known, the king funded a streamlined team to accompany Hernández on the expedition: one artist, one geographer, and one local guide. Each of these roles in fact required more than one person as the expedition traversed a varied countryside.²² The single pack horse and salary of 2,000 ducados per annum for three years in the New World appear from Hernández’s testament to have been supplemented by Hernández’s own savings, personal credit that he built from working as an anatomist at monastic hospitals, and from his son who doubled as his unpaid amanuensis.²³ Hernández’s son, Juan, helped

²⁰ Letter of Appointment from Philip II to Hernández dated 11 January 1570, Hernández and Varey, *Mexican Treasury*, 46.

²¹ In his 1580 letter to Benito Arias Montano, Hernández bemoans his first-hand trials while on the expedition: “What do I say? Why did it fall to me to test the medicinal plants on myself, And at the same time put my life at great risk?” On the American specimens that he sent to Spain he states, in the same letter, that he sent “twenty living plants, many seeds, and innumerable medicines” to Philip so that they “will adorn the gardens and hillsides”. Francisco Hernández, Rafael Chabrán, and Simon Varey, “‘An Epistle to Arias Montano’: Translation of a Poem by Francisco Hernández,” *Huntington Library Quarterly* 55, no. 4 (1992): 631-33. Surgeon Alonso López de Hinojosos (1535-1595) notes in his *Summa y recopilación de cirugía* (Mexico City, 1595) that he and Hernández conducted anatomical dissections together at the Hospital Real de Indios (founded 1556) and Hospital de la Concepción de Nuestra Señora (founded 1523) in Mexico City.

²² Hernández’s testament names three indigenous artists Antón, Baltazar Elías and Pedro Vázquez who painted the flora, fauna, and minerals that he identified. The cartographer was a strong-willed and charismatic Portuguese cosmographer named Francisco Domínguez y Ocampo whose varied talents and commitments left him unwilling to follow Hernández and map out only the regions where the plants were found. Hernández employed guides who knew the local flora and relied on packhorses to carry his supplies across the countryside.

²³ For a fascinating discussion of how a mix of Indigenous and Spanish anatomical dissections were practiced in early colonial New Spain see José Pardo-Tomás, “Opening Bodies in a New World: Anatomical Practices in Sixteenth-Century New Spain,” in *Anatome: Sezione, scomposizione, raffigurazione del corpo fra Medioevo e Età Moderna*, eds. Giuseppe Olmi, et al. (Bologna: Bononia University Press, 2012), 185-202. Also see: Alvar Martínez Vidal and José Pardo-Tomás, “Anatomical

to index the text and prepare clean copies of the manuscript for Hernández to then edit and annotate with interlineal as well as marginal changes.²⁴ The geographer Francisco Domínguez y Ocampo (ca.1520-1595) left the expedition for a number of years before returning to complete the maps. A new geographer was assigned during the interim. But it is unclear whether he drafted maps since none appear to have accompanied the text. Perhaps the maps were lost with the manuscripts at the Escorial, as the early print editions do not include them.

The Composition of the *Natural History*

The tremendous task of preparing a guide to the medicinal plants of New Spain and Peru was expected to take no more than three years, but the project ran late and went over-budget.²⁵ The tone of Hernández' letters to Philip II changed noticeably between the early days of the expedition and the end.

December 1571: The natural history of the Indies is proceeding with all proper care and diligence, and thus in the *eight months* since the work began, more than *800 new plants* have been depicted, with large figures on large paper... I have written of their very great virtues and of their immense usefulness...

(April 1572): I have completed two books, each one roughly comparable to Laguna's [1555 translation of] Dioscorides and the third one is nearly finished; *it is in Latin* so that this great gift of Your Majesty's may be communicated to all nations because this is the common language.

By late March of 1576, however, the initial thrill of discovery had given way to the toils of sustaining a long-term project and travelling constantly:

Theatres and the Teaching of Anatomy in Early Modern Spain," *Medical History* 49, no. 3 (2005): 251-80.

²⁴ These two hands appear in the draft manuscripts at the National Library of Spain, Biblioteca Nacional de España, "Francisco Hernández. Historia Natural de la Nueva España," (Sala Cervantes: MS 22436; MS 22437; MS 22438; MS 22439). Hernández's hand alone appears in the volume held by the Ministry of Haciendas Library in Madrid; see, Madrid Biblioteca del Ministerio de Hacienda, "Francisco Hernández. Antigüedades de la Nueva España," (MS 931). The Hernández manuscript held at the Royal Academy of History is a clean copy without edits and is bound in the gold-stamped, blue leather cover described by Cassiano dal Pozzo. (See above note 6.). The manuscript appears to have formed part of Philip II's personal library. Madrid Biblioteca de la Real Academia de la Historia, "Francisco Hernández. Antigüedades de la Nueva España, Tomo III," (MS 9/2101).

²⁵ By the end of the expedition Hernández writes that he has spent seven years toiling for the king:
"I entreat his Majesty who knows that I have been in his service, day and night, in New Spain for more than seven years occupied in the aforementioned expedition and History." Letter to Philip II, 24 March 1576 in Hernández and Varey, *Mexican Treasury*, 58. The Viceroyalty of Peru's botanical expedition had to wait until the eighteenth century.

I have delivered to the royal officials...with the fleet that is now ready to leave New Spain, *sixteen large volumes on the natural history of this land*...The work...has cost me my health and life...The descriptions treat concisely, the forms of the roots, branches, leaves, flowers, and seeds or fruit, its nature and degree, taste, smell and virtue *according to the evidence of [Native and local] doctors, gauged by experiment and the rules of medicine*, and the region and areas they come from. And even sometimes the climate in which they are found, the quantity applied, and their manner of cultivation... *I am still today finishing writing about additional discoveries*, and I am putting the final touches to the books that are still in rough draft, and producing fair copies of *four other books that will be of service to you*... and the 37 books of Pliny which I have finished translating and annotating.²⁶

Hernández's letter is both a record of shipping the royally commissioned volume, and an explanation for the time he has invested in the expedition; he lets the king know of his intense productivity over the intervening six years, and also points out that he has not just *translated* Pliny's thirty-seven books into Spanish—he has also updated and corrected the classical work of natural history based on his findings in New Spain.

In a letter dated September of 1572, two years after arriving in Mexico, Hernández mentions three volumes of images, drawn and painted in large figures on folio sized paper, of plants and nearly two more of birds and animals “ignotos a nuestro orbe” as well as a draft of what he was able to record about them.²⁷ The letter states that he is writing in Latin (and also producing a Spanish translation for local use in Mexico) about eight hundred plants which were previously unknown abroad.²⁸

Fifteen book manuscripts are finished concerning plants, animals, and minerals from this land and of great utility as much for the health of all as for the great excuse of spending for medicines; the books were not sent on the last fleet because I was planning to accompany them...and my trip was delayed until the next fleet in order for me to experience what I have written about as I am experiencing it in the hospitals which I am visiting.²⁹

Hernández's letters are littered with references to how thoroughly he and his aides recorded the physical characteristics of each plant. When his artists produced unsatisfactory illustrations he instructed them to use their thumbs as rulers to measure

²⁶ Hernández, "Cartas," 362ff. My emphases.

²⁷ Francisco Hernández letters to Phillip II illustrate how his initial expedition findings expanded into two dozen manuscript volumes.

²⁸ Barreiro, "Testamento." 479.

²⁹ Hernández, "Cartas," 376.

out the ratio and proportions of the live plant to the painted image.³⁰ He also seems to have used a schematic template for the text which resulted in three large volumes of more than 3,000 terse entries averaging 100 words in length—which included the numbers and relative sizes or proportions of the stems, leaves, flowers (if any), and roots as well as the illnesses or conditions for which the plant was effective.

When Philip II requested that Hernández extend his expedition to include Peru, the king must have been thinking about travel distances between states in terms of the European countryside which he had crossed many times in his youth on horseback with his court.³¹ But Hernández knew better than to attempt it. Between Mexico City and Lima, the overland distance is four times greater than the distance from Madrid to Flanders and would have crossed zones of intense pirate activity.³²

Due to my [advanced] age and ill health there is no way [that I will be able] to travel to Peru, I do not even know if it will be possible for me to return to Spain [in this state] despite my great desire and my great need to go there for the sake of printing, without which everything [that is, the results of this expedition] will be lost, as well as for the other things which relate to Your Majesty's service.³³

Based on the evidence of the extant manuscripts, Hernández complied with and was well-suited to the monarch's sober approach to data collection and direct, precise language in an age when baroque stylization and suggestive generalizations were the norm in cultured writing. His natural historian colleagues made use of a similarly direct register but were less concerned than Hernández with establishing a tone of objectivity. Nicolas Monardes (1493-1588), for example, employed a breezy, salesman-like use of anecdotes to illustrate the benefits of individual herbs: "A knight who for years had difficulty keeping his food down, used this oil of the 'Fig Tree from Hell' for his stomach and never vomited again."³⁴ By comparison, Hernández's manuscripts are spare with dense descriptions and contain few flourishes. The materialist rather than metaphysical focus of Hernández's *Natural History* results in refreshing depictions of indigenous *materia medica* where he refrained from the

³⁰ Hernández, Chabrán, and Varey, "Epistle," 631.

³¹ Kamen, *Philip*, Kindle loc.1002.

³² William Dampier, *Buccaneer Explorer* (London: The Folio Society, 1994), 324. Dampier describes the Panama isthmus as exceptionally perilous to travellers during the seventeenth century. Pirates and Maroon communities dwelling there contended with malarial swampland and dense jungle.

³³ Francisco Hernández and Germán Somolinos d'Ardois, *Obras completas* (México: UNAM, 1959), 482.

³⁴ Nicolás Monardes, *Historia medicinal de las cosas que se traen de nuestras Indias occidentales* (Sevilla: Casa de Fernando Diaz, 1580), 5b.

negative portrayals of “indios” that are typical in contemporary history writing.³⁵ The manuscripts also show evidence of having been carefully re-read and corrected by their author.³⁶

Hernández’s methodology and preparation of the texts exhibit a keen attention to the king’s wishes. So what explains Philip’s dissatisfaction? The principal conflict which hindered the completion of the manuscripts appears to have been the result of a discrepancy between Hernández’s desire to produce a work on the scale of Pliny’s *Naturalis Historia* and the king’s hope for the work to be a handy, rather than comprehensive, manual to medicinal plants. This discrepancy plays itself out as a conflict over the provisions of time, staff, and funding for the completion of the project. A number of unexpected circumstances in New Spain, such as the outbreak of the *cocoliztli* epidemic,³⁷ the delays and physical strain imposed by travel, field work in novel cultural environments, as well as bureaucratic delays and prohibitions imposed by local governors left Hernández feeling thwarted and aged.³⁸ While these difficulties appear to have burdened him they did not diminish his ambitions for the scope of his work. These unexpected events caused delays in the completion of the manuscripts, which lowered Philip II’s estimation of Hernández’s suitability to prepare the book for publication. The king’s comments written on the cover of Hernández’s ninth letter, dated 20 March 1575, express royal annoyance: “I have read this and written to the Viceroy telling him that this doctor has frequently promised to send these books, but he never does send them; he is to pack them up and send them on the first ship for safe keeping”.³⁹

Significantly, the King had specified the objectives of the expedition but not of the “history” that was to emerge from it. “With regards to the said History,” Philip wrote, “since we understand that you will write it whenever it is convenient, we leave

³⁵ One of Hernández’ lesser known works, the *Antigüedades de Nueva España*, has not yet been studied for comparisons with the *Historia general de las cosas de Nueva España* which was produced by Sahagún and a crew of indigenous translators, interviewers, and informants between 1545 and 1590. The Florentine Codex—the most famous output of Sahagún’s research—was primarily a cultural and linguistic primer for missionaries and secondarily an *avant la lettre* anthropology project as it consisted of indigenous responses to a comprehensive survey of their beliefs and lifeways. Hernández’s one-volume *Antigüedades*, on the other hand, conveys his collector’s drive to describe the peoples as one more aspect of México’s geography.

³⁶ BNE mss, see footnote 23.

³⁷ See footnote 4 regarding the epidemic.

³⁸ Hernández, Chabrán, and Varey, “Epistle,” 629-32.

³⁹ Hernández and Varey, *Mexican Treasury*, 56 n. 35.

it to you.”⁴⁰ While the king indicates a measure of faith in Hernández’s abilities as a writer, it seems to have suggested to Hernández that the king valued his research notes and fieldwork over a publishable final product. Fieldwork took up the better part of his days and writing was left to evenings or breaks between site visits. The inevitable delays in writing did not come without unwanted consequences, however, and Hernández eventually lost the opportunity to see his work through to publication.

Hernández’s last will and testament, written in Madrid in 1578, includes information about his collection of books, medical instruments and another of his manuscripts which is now in Madrid at the Biblioteca del Ministerio de Haciendas “Antigüedades de la Nueva España.” While not forgetting the *indios* “who brought herbs” or his son Juan,⁴¹ Hernández makes clear his intentions for the sixteen volumes he produced in New Spain:

It is my will that *the sixteen volumes of books* about herbs and animals of the Indies be given to his Majesty the King Philip, our lord, *which his Majesty had among his treasures* and the description of New Spain along with more paintings of herbs and animals which are added among the sketches, tables, and paintings on pineboard along with the volume containing the five auxiliary books and the three volumes which are translated into the Mexican language [Nahuatl]...It is my will that all and any of my books which should be printed be dedicated and offered to his Majesty for whom they were made and for the most part by whose help and favour they were written.⁴²

Two years before he wrote his will, in a letter dated 26 March 1576, Hernández tells Phillip II that the sixteen manuscript volumes which contained the better part of his efforts had been entrusted to the officials of the Royal Armada. He mentions the multiple manuscript copies which he had produced: the king’s copy which will be kept at the Escorial Library; a draft manuscript of the same work in Spanish; and a translation of his manuscript into Nahuatl that he likely left in a hospital in Mexico City.⁴³

⁴⁰ México Archivo General de la Nación, "Instrucciones del Rey, Felipe II, a Francisco Hernández," (Reales Cédulas (Duplicado) 47262).

⁴¹ Madrid Archivo de Protocolos Históricos, "Testamento de Francisco Hernández," (1017 fol. 458a).

⁴² Hernández revised his will at least twice. "Testamento de Francisco Hernández (8 mayo 1578)" Archivo de Protocolos (Madrid), 1017, fols.329-333r. I found the scribe’s hand very difficult to read; fortunately it has been transcribed in: Barreiro, "Testamento," 493.

⁴³ The manuscript in Nahuatl has not been located.

Dissemination and Printing the *Historia Naturalis*

In 1577, despite Hernández's worries about his return voyage, he did make it home to Spain and was able to deliver the manuscript to Philip II. After being bound in the regal blue leather with gold stamping of the Royal Library at El Escorial, the story of its journey to print becomes complicated. When Philip finally received it in Madrid seven years after the start of the expedition, he assigned another of his court doctors, Nardo Recchi, to abridge the work prior to printing. Recchi—eager to retire to Italy—worked in Rome where a fresh scientifically-oriented intellectual community was just beginning to take shape. The timing was very good: Hernández's writings became a centrepiece of the Accademia dei Lincei's activities during its first 60 years from c. 1580 to 1640.⁴⁴

With its Nahuatl nomenclature and a textual organization based upon indigenous concepts of how the flora related to one another, the work was more an introduction to the "otherness" across the ocean than the convenient guide to new medicines which Philip had in mind. While Hernández had experimented with organizational strategies for his work in his different drafts, for his final manuscript copy he settled on a conflicted compromise of plant genus and alphabetized subgroupings based on the Nahuatl plant-name etymologies, which in some cases included categorical slippage: the Nahua names implied certain associations between the botanical features of the plant and the plant's medicinal uses when naming it, and these etymological connotations were lost in the translation to European languages.⁴⁵

A reader in Madrid would have found it difficult to know—unless specified by Hernández—whether exotic botanical items were variants of plants also growing locally.⁴⁶ If the number of imported plants was small, it might have seemed in the end

⁴⁴ Raquel Álvarez Peláez, "La obra de Hernández y su repercusión en las ciencias naturales," *Asclepio* 47, no. 2 (1995): 30ff; Freedberg, *Eye of the Lynx*, 245ff.

⁴⁵ Varey offers as an example, the case of plants which excrete milky liquids sharing Nahuatl etymologies with other plants that do not have such secretions but were believed to aid in the milk production of mothers. Although the associations with milk in Nahuatl likely struck Hernández as a confusion of categories, he relied upon native herbalists and recorded his data using Nahuatl-language plant groupings; Hernández and Varey, *Mexican Treasury*, 36. Also see the discussion of Hernández's use of Nahua concepts in José López Piñero and José Pardo Tomás, *Nuevos materiales y noticias sobre la Historia de las plantas de Nueva España de Francisco Hernández* (Valencia: CSIC, 1994), 43ff.

⁴⁶ In fact there were exotic gardens created by sixteenth and seventeenth century Spanish collectors of Americana. The objective they shared was a desire to recreate the environments of the Americas; see, Rafael Chabrán, "Leonhart Fuchs in the Library and Garden of Vincencio Juan de Lastanosa: Maize, Chile, Narcissi and Tulips," in *The Gentleman, the Virtuoso, the Inquirer: Vincencio Juan de Lastanosa and the art of Collecting in Early Modern Spain*, ed. Mar Rey Bueno (Cambridge: Cambridge Scholars Publishing, 2008), 172-93.

a fruitless labor to Philip to have lists of foreign medicinal plants and practices without the specimens or knowledge of how to make use of them. The illustrations should have aided in the identification of the plants but these were bound in separate volumes and remained incompletely cross-referenced with the text. Moreover, the Nahua referred to similar looking plants using the same names to which Hernández added placenames or other identifying labels to disambiguate and differentiate them.⁴⁷

In preparing Hernández's manuscripts for publication, Recchi reorganized the sections on medicinal plants, deciding to follow Dioscorides's groupings of *materia medica*: aromatics, animals, herbs, roots, and minerals in *De materia medica* (c. 60CE).⁴⁸ Recchi did not alter the wording of Hernández's *Natural History of New Spain* noticeably but did abridge the original text and capped it with an Introduction that invokes Dioscorides' concerns for reliability and methodical knowledge.⁴⁹ With less regard for the Nahua etymologies than Hernández, Recchi made the work amenable to readers who hoped to use it as a tool for medical reference as the king had envisioned. Recchi penned his reorganized version of the text before the print edition could be set in type, and this manuscript in turn became an additional source for the dissemination of Hernández's findings.

After the abridgement by Recchi, the evidence is thin for the period during which Hernández's manuscript of the *Natural History of the Plants of New Spain* was to be printed in Philip's court with the help of Hernández's ally and the king's preferred architect, Juan de Herrera (1530-1597). Initially, Recchi feared invoking Philip's displeasure by divulging too much pre-publication detail about the abridgement, but the mystery only inspired more curiosity among European botanists and budding Italian naturalists. Recchi reluctantly showed his personal copy of the Hernández manuscripts and illustrations to private individuals in his home; meanwhile in Madrid, Juan de Herrera organized the early stages of the abridgement's printing at the royal press. Scholars do not know exactly who shelved this original print run in Madrid or what became of the type set by the king's compositors. Suspicions of Inquisitorial censorship have recently been posited but again the

⁴⁷ BNE Mss 22436-22439.

⁴⁸ During the reign of Nero (r. 54-68CE), the Greek physician and botanist, Pedanius Dioscorides (40-90CE), traveled widely with the Roman imperial army. Dioscorides grouped his findings into five sections which overlapped arbitrarily according to his needs for writing materials.

⁴⁹ "The Organization used by Dioscórides in his *Materia Medica* that will also be Used in this Treatise," in *De materia medica Novae Hispaniae*, eds. Raquel Álvarez Peláez, et al. (Aranjuez: Doce Calles, 1998 [1582]), 160-63.

evidence is as yet scant or nonexistent.⁵⁰ More likely, extended delays over the image engravings led to the entire project's abandonment.

After Recchi had died in 1595, the Accademia dei Lincei published Recchi's abridged manuscript of Hernández's *Natural History of New Spain*. During his lifetime Recchi had refused to allow the publication for fear of breaking his contract with Philip II, but following Recchi's death, the Accademia purchased the manuscript from his nephew. The Accademia rightly guessed that the Spanish Crown had by this time forgotten about the manuscripts and went ahead to print their own edition. It became the standard edition until the eighteenth century when Hernández's draft copies were found at the Jesuit Colegio Imperial, transcribed, and published by Casimiro Gómez Ortega. But before it had even been published, Recchi's manuscript copy of the Hernández manuscript was highly sought after. It circulated among European botanists alongside copies of the Escorial manuscripts. Editors and excerptors made selections and translations from the Latin original held at the Escorial.⁵¹

One unknown manuscript copy of the work arrived in New Spain ca.1605 by way of a Dominican missionary, Francisco Ximénez, who had received it from a Dominican friar while stationed in the Caribbean. Ximénez translated selections from the original Latin into Spanish and published the work in Mexico City in 1615, where it was used as a medical guide not unlike what Philip II originally requested, but this time without any ties to the monarch or the deceased Recchi and Hernández. Ximénez called his condensed Spanish-language versión of the Hernández manuscripts: *Four books on the Nature and virtues of plants and animals that are used Medicinally in New Spain and the Method and correct preparation for administering them according to the work that Doctor Francisco Hernández wrote in Latin, which is very useful for all types of people who live in settlements and towns where there are no doctors or pharmacies. Translated with the addition of many 'simple' and 'composite' recipes and many other secret curatives by Friar Francisco Ximénez, of the Convent of Santo Domingo in Mexico City*. The author states in his 'Note to the Reader' that, when he

⁵⁰ Simon Varey, Rafael Chabrán, and Dora Weiner, eds., *Searching For the Secrets of Nature: The Life and Works of Dr. Francisco Hernández* (Stanford: Stanford University Press, 2000), 16.

⁵¹ Scholars are unsure about the readership of a third draft copy which Hernández left in New Spain as a gift to the Hospital de Jesús in Mexico City, other than that it was recovered thirty years later in *Verdadera medicina* (1607) by a visiting physician at the hospital, Juan de Barrios.

was ill, he had been given a pirated copy of either the Escorial manuscripts or Recchi's unpublished manuscript.

Having an interest in matters of natural history and medicinal plants made Ximénez an ideal recipient of this chance gift on his journey to New Spain. Like Hernández before him, the Dominican friar Ximénez spent some years administering to the infirm at a hospital in the environs of Puebla de los Angeles near Mexico City where he finished his selections from an unofficial manuscript copy of Hernández's *Natural History*. His *Quatro libros de la naturaleza*, a faithful translation into Spanish, selects remedies which he found useful and uncomplicated. Ximénez's autobiographical remarks suggest that his interest in the topic of medicinal plants developed from his own experiences of illness while traveling. Following Ximénez, a series of unofficial excerpts and publications of the text found their way into a broad swathe of early modern botanical and pharmacological works in Europe and even East Asia.⁵²

Simon Varey's studies on the dissemination of Hernández's research demonstrate that a community of readers had not only begun to form before its first appearance in print in 1615, but manuscript editions continued to influence other scientists and medical practitioners long after the printed editions came out.⁵³ For example, Flemish botanist Carolus Clusius (1526-1617) wrote to a German colleague, Joachim Camerarius the Younger (1534-1598), in a letter dated 20 February 1597:

I remember that when I was living in Frankfurt, some people returning there from Naples told me that they had seen a huge number of plants, birds and quadrupeds depicted in their own colours, at the home of a certain doctor [Nardo Recchi] of the King of Spain, to whom they had been introduced by Giovanni Battista della Porta.⁵⁴

⁵² Raquel Álvarez Peláez, "Estudio introductorio," in *De materia medica novae hispaniae libri quatuor*, eds. Raquel Álvarez Peláez, et al. (Aranjuez: Doce Calles, 1998), 21ff. The Philippine Islands were in many ways an extensión of New Spain, and its earliest European settlers prepared their journeys in Mexico City. Crown-funded botanical expeditions to the islands, such as Juan de Cuellar's (1786 - 1797) incorporated the natural histories prepared by earlier missionary-explorers. On display at the sixteenth-century Augustinian monastery of Intramuros, Manila, are printed editions of the earliest botanical works concerning the Philippines.

⁵³ Simon Varey and Rafael Chabrán, "Mexican Medicine Comes to England," *Viator* 26, no. 1 (1995): 333ff; "Medical Natural History in the Renaissance: The Strange Case of Francisco Hernández," 134ff.

⁵⁴ Freedberg, *Eye of the Lynx*, 252. A year later in Leiden, Clusius was still wondering about the Hernández manuscripts. A reply to him regarding his questions about the manuscripts from Ferrante Imperato in Naples dated 7 January 1598 demonstrates Clusius' continued fascination, see: Giuseppe Gabrieli, *Contributi alla storia della Accademia dei Lincei* (Roma: Accademia Nazionale dei Lincei, 1989), 732.

Clusius's interest in American plants predated 1574 when his Latin translation of Nicolás Monardes' *Historia Medicinal* came out as *De simplicibus medicamentis ex Occidentali India delatis*

Varey's chronology puts Nardo Antonio Recchi's manuscript compendium of the Natural History at the start of a long line of printed editions and makes clear two unexpected textual trajectories.⁵⁵ The first, mentioned already, was the small print run of Hernández's work edited by Ximénez, which found its way into northern European botanical works by De Laet, Lovell, and Sloane. The second edition, by the Accademia de Lincei, placed Hernández's work in a central project of scholarly investigation and subsequent publications with ties in France, Spain, Flanders, Italy, and, Asia, sometimes via religious orders.⁵⁶

In 1614 Cesi, the founder of the Accademia dei Lincei, planned a fact-checking expedition to New Spain. Johannes Faber and Theodor Müller were charged with verifying the description of flora and fauna in Hernández's *Historia Natural*. This fact-checking expedition proceeded only as far as visiting the original manuscripts at the Escorial. Faber then proceeded to publish an annotated edition of Hernández's work as *Animalia Mexicana descriptionibus scholiisque exposita* in 1628, but focused on the animals rather than the plants. And in the same year the Accademia planned its own edition of Hernández's botanical writings as: *Rerum medicarum Novae Hispaniae thesaurus* (1651), also known as the *Tesoro Messicano*. When the Accademia selected Hernández's *Historia Natural* as a key publication it simultaneously published Galileo's works as well as the first book about bees viewed under a microscope for the Barberini Pope Urban VIII—who had bees on his family shield. Between 1625 and 1650, the academy also advanced the use of microscopes for botanical investigations.

Meanwhile, in 1615, across the ocean at the printing house of the widow of Diego López Dávalos in Mexico City, appeared two hundred quartos of Hernández's work edited and translated from Latin by Ximénez. Such an insignificant print run as

quorum in medicina usus est. Clusius maintained correspondence with Spanish intellectuals such as Benito Arias Montano, Simón de Tovar, and Juan de Castañeda.; see Álvarez Peláez, "Estudio," 63 n. 69.

⁵⁵ Varey has identified two dozen authors who excerpted, translated, and sometimes plagiarized Hernández's work before the year 1700. Some of these notable excerptors include Johannes de Laet (1630), Juan Eusebio Nieremberg (1635), Georg Marcgraf (1648), Robert Lovell (1659), Henry Stubbe (1662), John Chamberlayne (1671), Hans Sloane (1707). Three Spanish-language excerpt editions were produced in New Spain within forty years: Francisco Ximénez (1615), Juan de Barrios (1607) and a text by an obscure chaplain of the last hospital where Hernández worked before returning to Spain.

⁵⁶ Varey's chronology includes the principal as well as the lesser-known intermediate readers, copyists, and extrapolators to illustrate the wide reception of Hernández's work.

that of the *Quatro libros* in an apparently out of the way place should not have been noticed in northern Europe. But Dutch authors, in particular, noted Hernández's achievement: by 1630 Johannes de Laet, a director of the Dutch West India Company, translated Ximénez's edition of Hernández's work back into Latin; De Laet's excerpts were later translated by others into Dutch and published in *Beschrijving van West-Indie* (Leiden) by the successful printer Elsevier; in 1633 De Laet included more of Hernández's work in the *Novus Orbis* (Leiden, Elsevier); and in 1640 Elsevier published a French translation of De Laet's *Novus Orbis*. A different selection from the Ximénez edition appears in Abraham Munting's *Naauwkeurige Beschrijving der Aardgewassen* (Netherlands, ca.1696).⁵⁷ Dutch botanist Petrus Houttuyn (1648-1709) also had access to the *Quatro libros*.

The known transmission of Ximénez's *Quatro Libros* continue from the Netherlands to London. The physician Robert Lovell included the medicinal properties of more than ninety Mexican plants in his *Pambotanologia* (Oxford, 1665). Other English writers such as Henry Stubbes in 1662 and John Chamberlayne in 1685 cite Hernández's observations on cacao and chocolate. By 1707, Sir Hans Sloane's index of Jamaican plants incorporated Hernández's work via the *Quatro Libros*. Other scientists, such as Linneaus and Plumier, mention it even though they appear not to have read the work.⁵⁸

Some of the earliest readers and admirers of Hernández's work helped bring Recchi's edition to press. Della Porta's reply to Ulisse Aldrovandi about Recchi preparing the manuscript for print shows that European scholars not only gossiped about a work of Mexican flora and fauna but awaited its publication with bated breath:

The king asked his Council in Madrid to examine the book and he was told that it had been a great expense (that 80,000 ducats had been spent on it) for little benefit...This greatly wounded the poor doctor [Hernández]... They then assigned Marco Antonio Recchi de Monte Corvino to it... He has selected six hundred plants and animals, and the king is now having its engravings made and we will have it soon. [Recchi] has been paid an advance of 400 ducats...⁵⁹

⁵⁷ Another northern European edition containing 160 entries from Hernández's work was published by Juan Eusebio Nieremberg: *Historia naturae, maxime peregrinae* (Moretus: Antwerp, 1635).

⁵⁸ Paoli, "Vicisitudes," 156.

⁵⁹ Letter from G. B. della Porta to Ulisse Aldrovandi, Biblioteca Universitaria di Bologna: Mss. Aldrov. 136 vol. XIII. c. 294r, Vol.XVII, c.53. Quoted in Álvarez Peláez, "Estudio," 57.

More evidence of word-of-mouth communications about the manuscripts are found in Ferrante Imperato's letter to Charle de L'Ecluse on January 7, 1598.⁶⁰ In summary, at least twenty-three readers of Hernández's novohispanic compositions from across Europe and at least two in the Americas before the year 1700 published selections of his work.⁶¹

18th and 19th Century Historiography and "Reappearances" of the Manuscripts

Unmentioned by twentieth century historians but apparently of significant interest during the nineteenth century, in the style of a bookish Umberto Eco mystery, the very manuscripts that Hernández had delivered to Philip II in 1577 were thought to have reappeared in 1805 and again in 1836. The supposed discoveries reflected a heightened interest in the flora of Spain's soon-to-be former colonies, spurred by Linnaeus and other botanists' desire to classify the natural world.

The Bourbon Crown funded natural history expeditions motivated by the monarchy's colonial reforms in public health and medicine as well as the desire to apply Linnaean taxonomic categories to American flora and fauna.⁶² In the 1760s, Casimiro Gómez Ortega discovered the Hernández draft manuscripts at the library of the Jesuit Colegio Imperial in Madrid. Gómez Ortega proceeded to direct the Royal Botanic Gardens (from 1771) and oversaw the cultivation and study of plants from the Americas and Philippine Islands within the botanic gardens in Madrid—just as Recchi and others had done under Philip II at the botanic gardens in Aranjuez.⁶³ As director of the botanic gardens, Gómez Ortega oversaw the botanic expeditions, and he pushed

⁶⁰ See footnote 53.

⁶¹ Two dozen readers aided the dissemination of Hernández's works before the year 1700: Hernández's son, King Phillip II, Recchi, Ximénez, Pomar, Acosta, Colonna, Lopez, Riti, Cesi, Faber, Müller, Barrios, de Laet, Nieremberg, Piso, Lovell, Stubbe, Chamberlayne, Ray, Newton, Munting, Petiver, and Sloane. Hernández and Varey, *Mexican Treasury*, xvii-xviii.

⁶² The Enlightenment-era Bourbon Crown funded five more natural history expeditions during the second half of the 1700s: Baltasar Manuel Boldo's expedition in Guantánamo (1796-1799); José Celestino Mutis in New Granada (1760-1808); Joseph Dombey, Hipólito Ruiz, and J. Pavón in Peru (1777-1788); Juan de Cuéllar in the Philippines (1785-1795); Alejandro Malaspina with Antonio Pineda, Tadeo Haenke, and Luis Neé mostly in the Pacific (1789-1794). Other natural history expeditions which referenced Hernández in their correspondence took place during the nineteenth century; the most prominent was the Scientific Commission of the Pacific (1862-1866) headed by zoologist-explorer Marcos Jiménez de la Espada (1831-1898); see Manuel Almagro, *Breve descripción de los viajes hechos en América por la comisión científica ... de 1862 á 1866* (Madrid: Rivadeneyra, 1866), 7; María de los Angeles Calatayud Arinero, *Catálogo de las expediciones y viajes científicos españoles a América y Filipinas (siglos XVIII y XIX)* (Madrid: CSIC, 1984), 361.

⁶³ Gómez Ortega oversaw the botanical expeditions to Peru and Chile by Hipólito Ruiz and José Pavón from 1777 to 1788, as well as Juan Cuéllar's from 1786 to 1801 in the Philippines.

for a new expedition to New Spain and Upper California (1787-1803) to test Francisco Hernández's *materia medica*.⁶⁴ In 1803, naturalists and expedition members Martín Sessé y Lacasta (1751-1808), Vicente Cervantes (1755-1829),⁶⁵ and José Mariano Mociño's (1757-1820) returned with a collection of botanical illustrations and specimens.⁶⁶ Gómez Ortega's discovery of Hernández's draft manuscripts set the stage for further "discoveries" of the very texts Hernández had taken to Philip's royal court in 1577.

Late seventeenth-century histories of the Real Monasterio de San Lorenzo El Escorial explicitly identified the Hernández manuscripts among the many losses incurred by the great fire of 1667. Yet, hope for the lost botanical images remained. The French botanist Joseph Pitton de Tournefort (1656-1708) had already attempted to find the lost Hernandez manuscripts at the Escorial in 1688, and despite writing about his failure the early unofficial copies in circulation kept botanists' hopes alive. The British physician-naturalist Hans Sloane (1660-1753), whose personal collection

⁶⁴ The influence of Hernández's draft manuscripts upon the late eighteenth-century botanical expedition to New Spain is reflected in Sessé's letters from the very start; see Archivo Real Jardín Botánico "Documento 30 de enero de 1785", V.1,1,1 and V, 1,1, 3. Comparable references to Hernández's pioneering botanical expedition by members of the eighteenth-century expeditions to Peru, Chile, and the Philippines are also among the records at the Jardín Botánico and the Museo de Ciencias Naturales. Many of the documents produced and specimens gathered by Spain's eighteenth and nineteenth century scientific expeditions have moved between the archive of the Real Jardín Botánico and the historic library of the Museo Nacional de Ciencias Naturales (Madrid); see ARJB Registro 0003382 "Traslado al Gabinete de Historia Natural las colecciones procedentes de la Expedición, existentes en el Jardín Botánico—Madrid. 1880-07-17."

⁶⁵ During this expedition Cervantes played a significant role in the establishment of both a new faculty of botanical pharmacy at the Universidad Real de México and implementing a Linnaean taxonomy at the botanic gardens in Mexico City. His ideas were best received by youthful criollos, such as Mociño, whose support and interest buffered him from the resentment of local scientists. Well-established Mexican scientists perceived the systemic changes as a foreign imposition on par with the devastating Bourbon economic reforms which had demoted New Spain from a "kingdom" to a "colony" twenty years earlier. The Bourbon Crown's economic policies (1760s) set the stage for the Mexican War of Independence (1810-1821) which began during the unstable period of Bonaparte rule over Spain and the Indies (1808-1813).

⁶⁶ Mexican physician-naturalist, José Mariano Mociño (1757-1820) trained with Vicente Cervantes on the expedition and gathered specimens from what is today Guatemala and the Nuuchah-nulth (Nutmeg) region of British Columbia near Vancouver, Canada. In 1803 Mociño accompanied the expedition back to Madrid where he became president of the Royal Academy of Medicine. During a period of political turmoil immediately following Joseph Bonaparte's exit from the Iberian Peninsula, Mociño, an *afrancesado* (i.e. a Bonaparte supporter) entrusted his *Flora Mexicana* manuscript to the Swiss botanist Augustin Pyramus de Candolle (1778-1841) in Geneva where they both taught at the university. Before returning the manuscript to Mociño in 1819, Candolle had copies made of the illustrations by engraver Jean-Christophe Heyland whose images of the *Flora Mexicana* subsequently made him Candolle's preferred illustrator. Candolle is often remembered for having developed the concept of "Nature's war" which influenced Darwin's model of natural selection; see Harold Rickett, *The Royal Botanical Expedition to New Spain, 1788-1820: as Described in Documents in the Archivo General de la Nación (Mexico)* (Waltham: Chronica Botanica, 1947), 21, 55ff; Hervé Burdet, "Le récit par Augustin Pyramus de Candolle de l'élaboration de la *Flore du Mexique*, dite aussi *Flore des dames de Genève*," *Anales del Jardín Botánico de Madrid* 54, no. 1 (1996): 575-88.

of books seeded the British Library, also heard the rumors that Hernández's Escorial manuscripts survived the fire. He wrote in the preface to his *Voyage to Jamaica* vol. 1, (1707):

Hernández was sent by the king of Spain to search after natural productions about Mexico... Meeting with many of the plants he describes [during my own voyage] in Jamaica, I had a great mind to be satisfied about them and being told... [that the books were in] the king of Spain's library, in the Escorial... I wrote to Mr. Aglionby when he was envoy... to the court of Spain to procure a sight of the work and give me an account of it.⁶⁷

Hernández's notes on the flora and fauna of the Caribbean islands were lost or not incorporated into the Recchi edition of his natural history. Nevertheless, Sloane states that what he has heard of the Hernández's descriptions recalls Sloane's own American findings on the Caribbean islands.⁶⁸ Sloane recounts the disappointment shared by Aglionby and "other curious travelers" who had visited the king's library to see the Hernández manuscripts. Suspecting that the Escorial librarians were hiding the manuscripts, Sloane speculates that the originals were in Rome where the Academia dei Lincei had published Recchi's copy of the work by 1651.⁶⁹

Within Spain, physician and botanist José Quer y Martínez (1695–1764) had continued to propagate a hope of finding Hernández's royal manuscripts. As he wrote in his *Flora Española* (1762):

What a tragedy! The majority of Hernández's work fell victim to the voracious flames. Nevertheless, some fragments survived and I have held them in my hands; they made my eyes well up as I thought on the delicate drawings and the vividness of the colours of the plants, trees, and animales all by an indigenous artist. A few volumes remain of the herbarium with dried plants from the Americas and some from Spain.⁷⁰

Quer y Martínez may have found the same anonymous work that Sessé, and later Gallardo, mistook for Hernández's a half century later—they too noted the presence

⁶⁷ Hans Sloane, *A Voyage to the Islands... with [a] Natural History* (London: B.M., 1707), Preface, 8-9.

⁶⁸ Hernández and Varey, *Mexican Treasury*, 20.

⁶⁹ A record from the historic Escorial library catalogues indicates that Recchi returned the Escorial's Hernández manuscripts before 1595.

⁷⁰ Joseph Quer Martínez, *Flora española: Ó Historia de las plantas, que se crían en España* (Madrid: Ibarra, 1762), 38.

of dried plant matter within the codex.⁷¹ While Hernández never mentions attaching specimens to the pages of his manuscripts, some historians confused hearsay about the anonymous work of dried plants with the lost manuscripts.

The late eighteenth-century historian of the art of the Escorial, Fray Andrés Ximénez, followed earlier historians of the Biblioteca Escorial when he wrote that Hernández's works had perished in the great fire of 1667. But he also added a detail picked up from descriptions of the anonymous "discovered" herbal:

Books of inestimable interest and admiration perished in the fire. They were a history of all the medicinal plants of the Western Indies using indigenous pigments and the very leaves, roots, stems, flowers, and fruits attached within the codices. The author of this curiosity was a distinguished herbalist and physician named Francisco Hernández born near Toledo.⁷²

Misinformation spread between Quer y Martínez's history published in 1762 and Ximénez's in 1764; both mistaken and accurate details about Hernández's works appeared successively in print. The mingling of such data left room for the hope of rediscovery, and indeed Gómez Ortega found Hernández's draft—not the Escorial—manuscripts at a Jesuit library during the late eighteenth-century.⁷³

The extant authorial manuscripts, originally kept at the Jesuit Colegio de San Isidro (Colegio Imperial), are now split between the Biblioteca Nacional and the library of the Ministerio de Haciendas. It appears that there are five bound volumes of rough drafts which include the Latin text of the *De historia plantarum Novae Hispaniae*, the beginnings of a translation into Spanish of the same work, and a third work entitled "De Templo Mexicano". The sixth remaining manuscript volume, "De Antigüedades de Nueva España," bound with the royal shield on the front cover, appears to have begun as part of the set given to Philip II and was likely also housed at the Escorial library; it is presently available for consultation at the Academia Real de la Historia.⁷⁴ All six folio volumes are in Madrid.

⁷¹ Felipe Picatoste y Rodríguez, *Apuntes para una biblioteca científica española del siglo XVI* (Madrid: Tello, 1891), 142.

⁷² Andrés Ximénez, *Descripcion del Real Monasterio de San Lorenzo del Escorial* (Madrid: Marín, 1764), 208-9.

⁷³ Francisco Hernández and Casimiro Gómez de Ortega, *De historia plantarum Novae Hispaniae* (Madrid: Ibarrae Haredum, 1790), Praefatio, IV.

⁷⁴ I consulted the manuscript in April of 2014.

In 1836, in his essay on rare and curious books, bibliographer Bartolomé José Gallardo (1776-1852) wrote that he believed he had found the manuscripts and illustrations at the Escorial library:

While living with the friars at the Escorial and spending my days from dawn until dusk closed up in the historic library, I discovered in a back room of forbidden books thirteen folio volumes of Francisco Hernández's botanical works with illustrations of the herbal plants.⁷⁵

Gallardo added a touch of mystery to his account by stating that he had made his discovery in a secret room, where the work had lain unnoticed for decades. According to scientist Miguel Colmeiro y Penido (1816-1901), however, Gallardo actually found an unnamed herbal from the humanistic library of a diplomat to Italy Diego de Mendoza (1504-1575) that was added to the Escorial Library catalog in 1576 and survived the great fire of 7 June 1667.⁷⁶ Martín de Sessé had already found this book in 1805, and also believed it to have been Hernández's work.⁷⁷ He was even commissioned to produce engravings for the mysterious thirteen volume work but the costliness of the impression made it impracticable, and the volumes were put aside until Gallardo, during his retreat at the Escorial monastery, found them again in 1836.⁷⁸

The remaining mystery concerns the illustrations contained in all of the printed editions of Hernández's work. According to Chabrán, the original paintings (not drawings) were destroyed in the fire of 1667 although sixty survive in the Codex Pomar in Valencia.⁷⁹ The Pomar Codex was gifted by Philip II to the Faculty of "Herbes" at the University of Valencia. The Codex, named after Jaume Honorat

⁷⁵ Bartolomé José Gallardo, *Ensayo de una biblioteca española de libros raros y curiosos*, vol. 3 (Madrid: Gredos, 1968 [1888]), 177.

⁷⁶ Miguel Colmeiro, *La botánica y los botánicos de la Península Hispano-Lusitana: Estudios bibliográficos y biográficos* (Madrid: Rivadeneyra, 1858), 154. In addition to being a botanist, Colmeiro was dean of the faculty of sciences at the Universidad Central in Madrid as well as director of the Royal Botanic Gardens and a member of the Royal Academy of Medicine, the Royal Academy of Sciences, and the Spanish Royal Academy. His intellectual circle spanned the Enlightenment-era scientific societies of Madrid.

⁷⁷ Martín de Sessé y Lacaste directed the Royal Botanic Garden's expedition in 1787-1803 to New Spain to continue the work of Francisco Hernández. This eighteenth century expedition was cut short by unstable political conditions immediately preceding the Mexican War of Independence from Spain and France.

⁷⁸ See Picatoste y Rodríguez, *Apuntes*, 142. When I visited the Escorial in May of 2014, the director of the Real Biblioteca confirmed that the manuscripts were destroyed in the fire of 1667 and that the rumor, begun in the early eighteenth-century, still begets confusion among scholars.

⁷⁹ Hernández and Varey, *Mexican Treasury*, 4.

Pomar (c. 1550-1606), is a guide to the world's plants and selected animals as they were known by the late sixteenth century.

One of the manuscript volumes, Mss. 931 at the Biblioteca del Ministerio de Haciendas (Madrid) contains the text of several briefer works by Hernández and provide a glimpse of the author's experiences while in Mexico: "De morbo novae hispaniae anni 1576 vocato ab indis cocoliztli"—a report on the plague which decimated the indigenous population; "De provincial china seu Taibin quae dierum navigatione distat a philippis Liber"—a letter from the Philippines (arrived at Acapulco in 1576) by two fellow doctors who had collaborated with Hernández on the geographic descriptions of New Spain. This second work appears as an attempt to fulfil Philip II's request to report on the geography of Asian New Spain—the Pacific provinces—by relying on the work of others.⁸⁰

Within the text of his *Historia Natural*, Hernández references other unpublished, and now lost, works on the individual islands of the Caribbean which he had composed during the course of the journey: *Libro sobre la flora de las Islas Canarias*; *Libro sobre la flora de la Isla de Haití*; and the *Libro sobre la flora de la Isla de Cuba*. These smaller lost works were a trial run for structuring his natural history of New Spain as well as a series of introductions to the fauna and flora of the Americas.

Conclusion: Filtering from New Spain to Europe

Philip II instructed Hernández to provide the material for a practical guide to the medicinal uses of plants for potential recipients in Europe. Ultimately, however, the attempt to bring knowledge about novohispanic medicinal plants to Spain for immediate use proved more complicated and less immediate than the king had expected. Hernández excelled at the task of fieldwork; he extracted potentially useful information from first hand sources and recorded them. His texts then were inscribed by others into their printed works which highlighted the most appealing and memorable aspects of his raw material. The conflict between his comprehensive, humanist approach to the task and the vision of a practical guide which Philip II required, appears as a classic discrepancy between the task of meeting the

⁸⁰ Biblioteca del Ministerio de Hacienda, "Francisco Hernández. Antigüedades de la Nueva España." Somolinos observes that Francisco Hernández displayed a strong interest in the geography of Asia based on the titles of his briefer works, see Somolinos D'Ardois, *Vida y obra de Francisco Hernández*, 430.

requirements of funding, or in this case patronage, while maintaining a commitment to the primary sources and indulgence in a genuine curiosity for the task of research. Moreover, as the history of the text shows, an early Mexican imprint, and Hernández's *Historia Natural* more broadly, played important roles in the development of observational, experimental, and cultural sciences in Europe as well as the Spanish colonies. Most importantly, Hernández's journey and that of his writings exemplify the transoceanic movement of scientists, codices, and mixed Indigenous-European knowledges that concern this thesis.

Chapter 2 The First Large-Scale Astronomical Expedition (1583-1590): Jaime Juan and Francisco Domínguez y Ocampo

By the last quarter of the sixteenth century, Philip II desired an accurate map of his possessions—all of them. The mapping projects of his reign had already produced an internally consistent map of the Iberian Peninsula as well as attractive chorographic depictions of its cities to decorate the walls of his royal residences.¹ Maps of his possessions in the mid-Mediterranean and along the North Sea were either already underway or had already been represented visually to his satisfaction, but the overseas territories had not yet been systematically surveyed for accurate charting.

While internally consistent maps of a region can be produced with little reference to the larger imaginary web of parallels and meridians that tie the earth's geographies together, producing a map that accurately places the continents, and their orientations, in relation to the others was considerably more challenging.² An incomplete knowledge of the extent of the Asian and American coastlines magnified the cartographic difficulties. Ever willing to initiate ambitious undertakings for the sake of obtaining new knowledge, Philip's cosmographers aimed to map a world they had not seen, using a number of approaches including a survey of observations compiled in *Relaciones Geográficas* (1569-1612), a collection of forecasts of lunar eclipses (1577, 1578, 1581, 1582, 1584, 1588), and an astronomical expedition in 1583.³

This astronomical expedition of 1583 cut a course directly west from the Canary Islands across the Atlantic, New Spain, and the Pacific. It aimed to establish

¹ Mundy hints at the political uses of these chorographic maps of the Iberian Peninsula; the cityscapes were placed where visiting dignitaries would see their own regions' metropole beautifully depicted at the Palacio Real in Madrid. By contrast, the larger scale geographic maps of distant possessions were strategically arranged in the Palace-Monastery of El Escorial to celebrate the powers of the Crown. Mundy, *Mapping*, 7.

² Internally consistent regional maps required a cartographer's skills at surveying, measuring, and accurately unifying the sub-sections of a map into a single image. Some form of coordinate mathematics is required to achieve the goal with any degree of precision. Prior to Philip's mapping projects, the Mallorca Cartographic School had set the standard for visual accuracy in maps.

³ Héctor Velázquez Fernández, "Instrumentación, ciencia y epistemología: la relevancia de la observación novohispánica del eclipse lunar de 1584," *En-claves del Pensamiento* 2, no. 4 (2008): 122n.13.

the longitude and latitude of Manila along with the major cities of the Caribbean and New Spain.⁴ From 1583 to 1590 astronomer Jaime Juan, cartographer Domínguez de Ocampo,⁵ and royal armourer Cristóbal Gudiel produced charts of the empire's cities using a consistent set of measurement scales. The expedition worked as a collaborative project drawing on the expertise of a handful of professionals; as in the case of the *Relaciones Geográficas*, no single mapmaker need produce the total chart because the cartographers at the Casa de la Contratación (House of Trade) would later draw a complete map which represented the disparate maps together in a new totality. Their plan for how to accomplish the task illustrates a fundamental vision of the earth's surface as mathematically comprehensible. The Crown's possessions on three continents could then be represented with the greatest possible accuracy on a single map—a map which the viewer could read at a glance.

The aspiration to better know the relative locations of selected islands and continents became, a century-and-a-half later under Bourbon King Philip V (1700-1746), a grander one to define the shape of the globe by using astronomical observations. Two Spanish naval officer-scientists, Jorge Juan y Santacilia (1713-1773) and Antonio de Ulloa (1716-1795), accompanied a crew of French scientists—famously led by Charles Marie de La Condamine (1701-1774)—on the geodesic expedition of 1735. Juan y Santacilia and Ulloa produced half a dozen works of geography and natural history based on the expedition, including the *Observaciones astronómicas y físicas hechas en los Reinos del Perú* (Madrid, 1748) which recounts the calculations and methods used during the expedition. Quito served as the site to determine whether the earth thinned or bulged at the equator. Newton's calculations suggested a bulge at the equator whereas Descartes had posited it at the poles.⁶ A separate crew was assigned to take measurements in the northernmost region of Lapland, and Newton's calculations were confirmed.

⁴ Manila was the second capital city, after Cebu, of the Philippines, chosen for its broad harbour and distance from early pirate attacks. Manila was preferred over Cebu for a variety of reasons: Cebu's vulnerability to corsairs—Thomas Cavendish in 1587, Olivier van Noort 1600—seeking the goods of the Manila Galleon trade from China and Japan to Acapulco. The longitude of Cebu had been measured in the late 1560s by the Augustinian Martín de Rata (1533-1578) after accompanying the Urdaneta-Legazpi voyage of 1565; see footnote 34. Spain exchanged the Moluccas for the Philippine Islands with Portugal; the islands were (correctly) thought to be on the wrong side of the demarcation line. See, Luis Alonso Álvarez, *El costo del imperio asiático: la formación colonial de las islas Filipinas bajo el dominio español, 1565-1800* (Coruña: Universidade da Coruña, 2009), 29-34.

⁵ This is the same Domínguez y Ocampo who mapped Francisco Hernández's travels in Chapter 1.

⁶ Neil Safier, *Measuring the New World: Enlightenment Science and South America* (Chicago: University of Chicago Press, 2008), 6-8.

The Bourbon-era expedition differed from Jaime Juan's in so far as telescopes made it possible to determine longitude by observing the phases of the moons of Jupiter.⁷ Galileo had developed a method for timing the phases of Jupiter's four largest moons by 1620. During the eighteenth century this method was commonly applied to the problem of terrestrial longitude with the use of an instrument such as the Jovilabe, or alternately, by consulting tables of the planet's lunar phases.⁸ On this Bourbon era expedition, La Condamine also introduced a new set of standard units for measurement which was an early form of the metric system. Jaime Juan's large-scale astronomical expedition 1583-1590 was the first of a notable series of early modern geographic expeditions.

This chapter analyzes Jaime Juan's early large-scale astronomical expedition with Domínguez y Ocampo to highlight the principal role of the Spanish Crown in establishing standard practices for colonial science during the late sixteenth century. This chapter also traces the social networks of the royal architect, Juan de Herrera, in so far as they shaped the expedition and the study of mathematics by Spanish aristocrats who might later become governors in the colonies. This chapter examines documents kept at the Archivo de Indias (Seville): a salary contract, a voyage itinerary, a last testament, and the lunar observation of November 17, 1584. Historians Maria Portuondo and María Luisa Rodríguez Sala have in the last two decades brought this little known astronomical expedition to light.⁹ Rodríguez Sala has published the best biographical information known about the key scientists on the expedition by consulting archival documents kept at the Archivo General de Indias with related documents at the Archivo General de la Nación (Mexico City).¹⁰

⁷ Sixteenth-century instruments aided mathematics and the calculation of measurements whereas, from the first quarter of the seventeenth century onwards, scientific instruments enhanced human abilities to perceive nature—telescopes, microscopes, vacuum pumps. See, Jim Bennett, "Knowing and Doing in the Sixteenth Century: What were Instruments for?," *The British Journal for the History of Science* 36, no. 2 (2003): 129-50. In this chapter I employ a broader notion of "instruments" by including those books and maps that experimentalists traveled with and used in their work.

⁸ Galileo's method of celestial timekeeping consisted of charting the phases of Jupiter's moons. He affixed a ruler to his telescope and kept track of the moons' distances from the planet; their movements appeared regular and he could thus predict them with accuracy.

⁹ María Portuondo, "Lunar Eclipses, Longitude, and the New World," *Journal of the History of Astronomy* 40 (2009): 249ff; María Luisa Rodríguez-Sala, *El eclipse de luna: misión científica de Felipe II en Nueva España* (Huelva: Universidad de Huelva, 1998), 43ff. Also see: Velázquez Fernández, "Instrumentación," 115.

¹⁰ Rodríguez-Sala, *Eclipse*.

Portuondo has assessed the documents' astronomical precision to offer a nuanced appreciation for the mathematical skill involved in the project.¹¹

Building on their foundational work, my study concentrates on the scientists and their instruments in circulation across the Atlantic and Pacific because of their significance to the development of a scientific community in colonial New Spain. Mexico City with its aristocratic urban culture located midway between East Asia and the Iberian Peninsula, was a gathering place for scientific travellers where they exchanged and generated new ideas or made discoveries.

Backdrop to the Expedition: The Relaciones Geográficas

The *relaciones geográficas* initiated in 1569 and the Expedition of 1583 were related but distinct mapping projects. The *relaciones* project relied upon the mass distribution of a survey to regional and local administrators in the Spanish colonies.¹² A questionnaire, first composed by Alonso de Santa Cruz (1505-1567) during his decades as a cosmographer at the Casa de Contratación, asked imperial officials to record information about their localities. It inquired about the particulars of towns, their inhabitants, and their measurable distance from major cities to provide enough information to determine their coordinates. These numerical responses were necessary for any mapping the Casa could achieve. Question six of the survey requested the height of a fixed point in the sky, the North Star, that would be used by the Casa to calculate the distance of any site in the New Spain from the north pole. These data, when available, could be collated on a complete map at the Casa.¹³

¹¹ Portuondo, "Lunar Eclipses."

¹² For a collection of the varied *relaciones* questionnaires see, Francisco de Solano, ed. *Cuestionarios para la formación de la relaciones geográficas de Indias, siglos XVI-XIX*, vol. I (Madrid: CSIC, 1988), 9ff.

¹³ The sixth item of the 1577 survey as translated by Cline: "Give the latitude or the altitude of the Pole Star, at each Spanish town if it has been observed or determined or if there is anyone who knows how to observe it, or state on which days of the year the sun does not cast a shadow exactly at noon." Cline, "Relaciones Geográficas," 234-35, Appendix C. Identifying latitude was by the sixteenth century already a common practice used at sea and on land. If the appropriate astronomical tables were at hand, the altitude of the pole star was not necessary; latitude could be determined by using tables of the sun's height at midday along the equator every day of the year. The difference between what the table gave as the height of the sun and the height actually observed at any particular location, determined one's location north or south of the equator, hence latitude. A mid-sixteenth century discussion of both methods ("La determinación de la latitud mediante la altura del Sol" and "La determinación de la latitud mediante la altura de la Estrella Polar o de la Cruz del Sur") can be found in Pedro de Medina's *Arte de Navegar* (Valladolid, 1545). The problem of longitude, on the other hand, was one of determining how far east or west one was from the imaginary line running from the north to the south poles through a city such as Toledo, Madrid, Paris, Frankfurt, and from 1851 Greenwich.

The Santa Cruz survey was revised by Juan López de Velasco in 1577 and continued to be updated for greater effectiveness and clarity through 1648. Of the 317 known responses dated between 1579 and 1608, the vast majority were produced within the first five years of the original circulation of the questionnaire.¹⁴ The original survey included thirty-seven questions that grew to two hundred by the year 1600 in response to complaints about the ambiguity of particular sections. Such responsiveness to feedback in the effort to optimize data collection remained a notable characteristic of the Casa's techniques during the reigns of Philip II and Philip III.¹⁵ The Casa proved to be a more agile organization than the imperial administration, but the latter's bureaucracies did provide a structure through which surveys could be distributed and securely returned.

The means of obtaining mapable data was an early modern version of crowdsourcing. Colonial officials distributed the flysheet with specific instructions to town governors in the hinterlands; governors sent the responses to the appropriate viceregal administrator in Mexico City; his officials in turn sent them to the Casa in Seville. Responses varied in the degree to which they provided usable data; the maps in particular radically differed from one town to another, and extant responses demonstrate the preponderance of indigenous artists preserving the Pre-Columbian terms and ideograms of their regions.¹⁶ Some of the maps must have frustrated the Casa cosmographers because they lacked a common, standardized projection and scales for identifying distances between cities.¹⁷ The survey questions, however, were composed in such a way as to cover related topics from different viewpoints and thereby completed the textual picture of a locale's record.¹⁸

¹⁴ "A Census of the 'Relaciones Geográficas' of New Spain, 1579-1612," in *Handbook of Middle American Indians*, ed. Howard Cline (Austin: University of Texas Press, 1972), 326ff.

¹⁵ Ibid. Clinton Edwards, "Mapping by Questionnaire: An Early Spanish Attempt to Determine New World Geographical Positions," *Imago Mundi* 23 (1969): 17-28.

¹⁶ Mundy, *Mapping*, 97ff.

¹⁷ For examples of the maps see the Benson Online Collection of Relaciones Geográficas: <https://www.lib.utexas.edu/benson/rg/>

¹⁸ Mundy has interpreted the extant responses as reflecting a binary opposition between a preference for the "textual" by the Spanish and the "pictorial" by indigenous peoples during the sixteenth century. I would suggest, however, that the preponderance of indigenous artists creating the maps in the *relaciones geográficas* rather than simply supporting available evidence that the visual arts held a high status in indigenous culture and religion, also suggests something about the absence of Europe-trained visual artists outside of larger urban centres such as Mexico City. The viceregal patronage of European artists would have kept them close to major cities whereas the *relaciones* responses came primarily from previously unmapped hamlets and monastic villages. As for Mundy's suggestion that an absence of indigenous authors among the textual responses of the *relaciones* indicates a lack of interest in text-making among the Nahua, I would counter that Pre-Columbian codices as well as post-conquest Nahua histories do not support that conclusion; see James Lockhart,

The mapping facet of the *relaciones* project was ultimately beyond Santa Cruz and Velasco's ability to rationalize into a single output. In order for the project to work, the maps needed a common set of reference points; the irregularity of map projections and sui generis visual styles did not fit together like the jigsaw puzzle they were supposed to become. Nevertheless, the project successfully produced and preserved local chronicles as well as indigenous cartographic art, which were even at the time valued for their ethnographic content.¹⁹ As with other potentially sensitive documents, Philip II opted for the path of conservative politics—the responses to the *relaciones* surveys were kept on “closed reserve” to control their accessibility and prevent loss or theft.²⁰ Philip's court restricted access to politically sensitive texts to prevent information leakage and unwanted attention from the Inquisition.²¹

The Nahuas After the Conquest: A Social and Cultural History of the Indians of Central Mexico, Sixteenth Through Eighteenth Centuries (Palo Alto: Stanford University Press, 1992), 40; Susan Schroeder, "Writing Two Cultures: The Meaning of "Amoxitli" (Book) in Nahua New Spain," in *New World, First Nations: Native Peoples of Mesoamerica and the Andes under Colonial Rule*, eds. David Cahill, et al. (Portland: Sussex Academic Press, 2006), 18ff. Additionally, Spanish literary study among the Nahua was available to the elite descendants of the Nahua aristocracy and located primarily in the viceregal capital. (See Elizabeth Hill Boone, *Stories in Red and Black: Pictorial Histories of the Aztec and Mixtec* (Austin: University of Texas Press, 2008), 26, 29-31; David Webb, "Historia cronológica de la noble ciudad de Tlaxcala: A study of Juan Buenaventura Zapata y Mendoza's Nahua annals from seventeenth-century Mexico" (PhD Thesis, UCLA, 2005), 34ff.)

Regarding Spanish valuations of pictorial data, Bleichmar has written about the long history of “visual epistemology in the Hispanic world” and suggests that images were highly valued transmitters of knowledge within the networks of Spanish scientists. Bleichmar demonstrates how in early modern Spain, viewers of images produced in the colonies considered themselves participants in a kind of virtual witnessing, and discusses the Spanish tendency to collect large-scale visual data about natural history in the Americas; see, Daniela Bleichmar, "The Imperial Visual Archive: Images, Evidence, and Knowledge in the Early Modern Hispanic World," *Colonial Latin American Review* 24, no. 2 (2015): 236-66.

¹⁹ Mundy includes a helpful discussion of how indigenous artists visually inserted local lore, via toponymic symbols, that would have eluded the uninitiated viewer then and now; see, Mundy, *Mapping*, 142-43.

²⁰ Loss, theft, and unauthorized manuscript circulation were common occurrences in early modern scientific book collections, see: Silvia De Renzi, "Writing and Talking of Exotic Animals," in *Books and the Sciences in History*, eds. M. Frasca-Spada, et al. (Cambridge: Cambridge University Press, 2000), 151ff. Trabulse quotes Philip's note on page 13 of *Ciencia y Tecnología*. Philip wrote in the margins of López de Velasco's *Geografía y descripción delas Indias* (1574): “And having before now thought upon these books describing all of the Indies, it seems to me that on account of their quality and the inconvenience that would occur if these books were handled by many, as the case would be if the one of these books were missing or shifted from this Council [of the Indies], since the books belong to the Council it would be best if they were all gathered by the Council and placed in a closed cabinet.” The note suggests the king's appreciation for the curiosity these works might pique as well as the difficulty, if the works went missing, of otherwise finding chronicles based upon data synthesized at the Casa. See Agustín Barreiro and Francisco Hernández, *Los trabajos inéditos del Dr. Francisco Hernández sobre la gea y la fauna mejicanas* (Madrid: Asociación Española para el Progreso de las Ciencias, 1929), 18.

²¹ In November 1553, Philip issued a recall of Gómara's *Historia general* because the work justified the conquest of Tenochtitlan with Aristotle's notion of ‘natural slavery.’ See Cristián Roa-de-la Carrera, "Histories of Infamy: Francisco López de Gómara and the Ethics of Spanish Imperialism," (2005): 55.

Juan de Herrera's Role

The terrestrial coordinates of Manila, Acapulco, Veracruz, and Havana were needed for producing maps which established accurate political boundaries.²² Precise coordinates of port cities were a navigator's grail and key for the Spanish Crown's negotiations with Portugal—and increasingly during the seventeenth century, with the Dutch, English, and French—for territorial possessions in the Caribbean and East Indies. In 1493 Pope Alexander VI had issued the Bulls of Donation which divided the globe in two for his Iberian countrymen. At the time of the papal bulls, the charts and geographical coordinates from Columbus' voyages and Portuguese explorations had not yet been consolidated into the secret charts—*padrón real* and the *padrão real* by the Casa de la Contratación (Seville) and the Casa da Índia (Lisbon) respectively—as they would later be with the profusion of new data coming from across the Atlantic. Spain and Portugal renegotiated what became the Treaty of Tordesillas (1494) at different points during the sixteenth century.²³ The results of the Expedition of 1583 were among various attempts to clarify the line of demarcation between the two in the Pacific, although from 1580 to 1640 the king of Spain also held the Portuguese Crown and the matter eventually became moot. Nevertheless the Crown's mapping projects continued well into the seventeenth century.²⁴

²² For a discussion of the maps as strategic displays of the Crown's dominion see Mundy, *Mapping*, 8. For a survey of the cartographic outputs of sixteenth century Spanish explorers see Elías Trabulse, *Historia de la ciencia en México* (México: FCE, 1997), 53-55. Little scholarship on the early, local mapping projects directed from Mexico City by the Primera (1527) and Segunda (1530) Audiencia exists; however the first sixty years of viceroy-funded explorations in New Spain are outlined in Miguel León-Portilla, *Cartografía y crónicas de la antigua California* (México: UNAM, 2001), 57-70. For a collection of maps and accompanying documents produced by Jesuits on the frontier see, Ernest Burrus, *La obra cartográfica de la Provincia Mexicana de la Compañía de Jesús (1567-1967)* (Madrid: Porrúa, 1967), 9ff.

²³ The Protestant Reformation coincided with the first stage of Spanish conquest in the Americas, hence Papal Bulls lost whatever international legitimacy they may have held prior and the Treaty of Tordesillas underwent multiple renegotiations. During the later sixteenth and the seventeenth centuries, the twin commercial monopolies, Portuguese and Spanish, inspired the ire of emergent European powers (England, the Netherlands, and France) and resulted in the maritime predation that peaked in the 1650s. See Fabio López-Lázaro, *The Misfortunes of Alonso Ramirez: The True Adventures of a Spanish American with 17th-century Pirates* (Austin: University of Texas Press, 2011), 8-9.

²⁴ Evidenced by the ongoing *relaciones geográficas* and maps of military engineers hired to build forts along with the maps by explorers like Obregón who pressed northwards, and other entrepreneurial cartography by figures such as Cardona; see David Buisseret, "Spanish Colonial Cartography, 1450-1700," in *The History of Cartography*, ed. J.B. Harley (Chicago: University of Chicago Press, 2007), 1143ff; "Spanish Military Engineers in the New World before 1750," in *Mapping and Empire: Soldier-Engineers on the Southwestern Frontier*, eds. D. Reinhardt, et al. (Austin: University of Texas Press, 2010), 44ff. Mission cartography was another source of maps during this time, see "Jesuit Cartography," 113ff.

The royal architect Juan de Herrera (1530-1597)—Philip’s defacto science advisor—played a facilitating role as one of the expedition’s initial organizers. Herrera hailed from the landed gentry of Valdáliga in northern Spain and studied at the Universidad de Valladolid. He accompanied the royal court’s travels during the late 1540s and early 1550s becoming tutor to Philip II’s son, prince Charles II, in mathematics and astronomy. By 1562 Herrera had impressed the monarch with his technical skill in editing Alfonso X’s thirteenth-century *Libro del saber de astronomía* and was soon appointed royal architect of the Escorial Palace-Monastery.²⁵ Herrera’s role in setting Philip’s science agenda cannot be overstated. He is well known as the king’s architect but his influence in matters relating to the promotion of mathematical studies in Madrid is less known. As the first director of the Academia de las Matemáticas—founded 25 December 1582—he set a curriculum of mathematical and architectural training which was intended to prepare noblemen for administrative roles both at home and in New Spain.²⁶ Herrera edited volumes for the use of the Academia and for students more widely. When the books were only available in Latin, a forward-looking Herrera petitioned for them to be translated into Castilian in order to support the use of the vernacular in the Academy’s instruction.²⁷

Table 2.1: Herrera’s Book Selections for the Academy of Mathematics Curriculum

Leon Baptista Alberti’s <i>Diez libros de la Architectura</i> translated by Francisco Lozano (1582, Royal Printer Alonso Gómez)
Euclid’s <i>Perspectiva y Especularia</i> translated by Pedro Ambrosio Onderiz (1584, Widow of Alonso Gómez)
Iacome de Vignola’s <i>Regola de las cinco órdenes de Architectura</i> translated by Patricio Caxesi (1593, Patricius Caxesi)
Simón de Tovar’s <i>Examen y censura del modo de averiguar las Alturas de las tierras...</i> (1595, Rodrigo de Cabrera)
Cristóbal de Rojas’ <i>Teórica y Práctica de Fortificación</i> edited by Herrera (1598, Luis Sánchez)

²⁵ Catherine Wilkinson-Zerner, *Juan de Herrera: architect to Philip II of Spain* (New Haven: Yale University Press, 1993), 12.

²⁶ One of the founding documents of the Academia de las Matemáticas was transcribed by Picatoste 1891 in his *Apuntes para una biblioteca científica del siglo XVI* and appears in López Piñero, Portela Marcos, and Navarro-Brotóns, *Materiales*, 21.

²⁷ Luis Cervera Vera, *Intervención de Juan de Herrera en ediciones de libros* (Madrid: Instituto de Valencia de Don Juan, 1996), 20.

Source: Cervera Vera, *Intervención*, 20

Herrera, who designed scientific instruments, made the dogged issue of longitude and its concomitant politics come to the fore during his time spent in Portugal as part of Philip II's entourage.²⁸ His design for a tool to calculate longitude was patented by the king for ten years beginning December of 1573 and put to use in the Galleon Armada.²⁹ As described in an acknowledgement letter from a royal cosmographer of the Armada on 8 January 1574, it comprised "a walnut-wood board with a circle divided into three-hundred sixty segments, of about a square metre in size, with two horizontal rulers of the same length; the said instrument is used for longitudes."³⁰ The invention, which does not survive, also contained more wooden parts: a quarter of a one-metre-long circle divided into ninety equal segments (perhaps upright), an additional circular plate a third of the width in addition to an overlapping hemisphere spanning the width of the entire board. Two rulers of alloyed zinc and copper of slightly more than a metre in length serve to identify the latitude at any hour of the day. To complete the piece, a small pear tree wood level, one-half metre in length with graduated markings forms part of the invention. These descriptions suggest that the invention was a rather large wooden astrolabe with an upright quadrant and plumb bob attached. The description, however, was written more as an inventory of the physical objects rather than as a guide to imagining the instrument; instructions for using the tools are not included. Herrera invented other navigational instruments, and some are likely to be among the 10,500 historic instruments housed at the Museo Naval in Madrid.³¹ Herrera ultimately received little pecuniary benefit

²⁸ Portuondo, *Secret Science*, 223-30. Herrera also collected instruments; Cervera Vera has found documentary evidence of Herrera's tools for drawing and building instruments, Herrera's "ynbenzi3n," and, by my count, more than fifty other nautical or astronomical instruments in his last testament. Luis Cervera Vera, "Instrumentos náuticos inventados por Juan de Herrera para determinar la longitud de un lugar," *Llull* 20, no. 38 (1997): 143-60; *Inventario de los bienes de Juan de Herrera* (Valencia: Albatros, 1977), 64-65; 67-74.

²⁹ Seville Archivo General de Indias, "Privilegio del Rey, Felipe II, a Juan de Herrera para la constu3cc3n de instrumentos que determinan longitudes," (Indiferente General, 426, Libro I, fol. 275).

³⁰ "Conocimiento de Alonso Alvarez de Toledo, cosm3grafo de su Majestad en la armada de los galeones, de los instrumentos de Juan de Herrera" Archivo General de Indias, Sevilla, *Secci3n de Patronato*, Legajo 259, ramo 58. Transcribed in Cervera Vera, "Instrumentos," 152, Appendice II.

³¹ Ibid. The Museo Naval was founded as one of the Bourbon Crown's Enlightenment-era institutions in 1792 by don Antonio Vald3s y Fern3ndez Baz3n, Charles IV's Secretary of the Navy.

from his designs even as he remained committed to the project of training Spain's noblemen to use applied mathematics for data collection in the New World.³²

The nautical instruments and techniques of Canary Islander, Juan Alonso, were also available to the court at the time. By 1570, Alonso had designed a tool "for measuring the height of the sun at any time of day..., for knowing the distance between places according to longitude without observing eclipses...and for navigating east to west with remarkable facility and certainty."³³ After hearing of the device from a regent of the Audiencia in the Canary Islands, Fernán Pérez de Grado, Philip requested on 4 August 1571 that Alonso's instrument be sent to Madrid so that its designer might be rewarded if it were indeed as useful as it sounded. Seven months later the regent's two sons travelled to the royal court and carried Juan Alonso's written "método." Alonso's text asked for "men of science" to examine his work and recommended his youngest son for the trials of the instrument at sea because of the latter's tacit knowledge and sailing experience.³⁴ While the story breaks off without further documentation, if Alonso's tools and methods were deemed useful in Madrid, they would have influenced Juan de Herrera's subsequent instrument designs.

Herrera recommended Jaime Juan to Philip II while they were all in Lisbon in 1581/82, attending Philip's accession to the throne. Herrera understood the political significance of the cosmographic data, which were also important to the Academy of Mathematics. He proposed a plan to settle the questions of latitude and longitude which had vexed the Casa's mapmakers since the Treaty of Zaragoza (22 April 1529) had specified the antemeridian to the demarcation line established by the Treaty of Tordesillas (1494).³⁵ Identifying the borders of the empire would settle disputes with the Portuguese over islands in the East Indies as well as define shipping routes.³⁶ Few biographical details exist for Jaime Juan's early life. He hailed from Valencia and the

³² Herrera, Díaz, and Vera, *Institución*, 20-21.

³³ Eustaquio Fernández de Navarrete, *Memoria sobre las tentativas hechas y premios ofrecidos en España al que resolviera el problema de la longitud en la mar*, vol. XXI, Colección de documentos inéditos para la historia de España (Madrid: Viuda de Calero, 1852), 17-19.

³⁴ *Ibid.*

³⁵ Portuondo, *Secret Science*, 66-67.

³⁶ As stated in note 4, an earlier determination of longitude of the Philippine Islands took place nearly twenty years earlier in 1564 on Miguel López de Legazpi's voyage to Cebu. Mathematician and Augustinian friar Martín de Rada travelled as a missionary from Mexico City on the voyage and used a "medium-large instrument to measure the longitude from Toledo" according to the testimony of Augustinian circumnavigator Andrés de Urdaneta. Rada's figures were regarded as provisional, hence the need for Jaime Juan's expedition; see, Fernández de Navarrete, *Memoria*, XXI, 21.

best available information about his life comes from texts which record his participation in the lunar observations of 1583. He was likely a gifted mathematician.

Table 2.2: List of Instruments as named and described in the *Instrucciones*³⁷

1. A marble tile – for a level surface upon which to place instruments when observing the meridian
2. An instrument – that can find the meridian with precision
3. Another instrument or curved ruler – for identifying the number of degrees and minutes that the needle points east or west once the meridian has been established
4. Another instrument or large quadrant – for finding the precise elevation of the pole once the meridian has been established
5. Another instrument – for use at sea and on land at any time of day, to find the elevation of the pole and the meridian or how much the compass differs from true north
6. An instrument – that is large and horizontal with which pilots and mariners are able to find (with the aid of the last instrument mentioned) their current distance from the place of their original departure

Source: AGI, Indiferente, 740. N. 103

The Instruments of the Expedition

Jaime Juan as chief astronomer on the expedition recorded naked-eye observations using astrolabes and quadrants, the norm in early modern Europe. Since the earliest days of exploration sailors and viceroys transported both instruments to the Americas.³⁸ Both astrolabes and quadrants originated in the Ancient world and were improved upon during the Middle Ages by Arab astronomers. Astrolabes, used for determining latitude or local time, typically consisted of a circular brass disc divided into 360 equal parts with a series of thin plates overlain that display a portion the celestial sphere and a movable pointer for indicating particular stars.³⁹ Jaime Juan

³⁷ Transcribed in María Luisa Rodríguez-Sala, "La misión científica de Jaime Juan en la Nueva España y las Islas Filipinas," in *El eclipse de Luna: Misión científica de Felipe II en Nueva España*, ed. María Luisa Rodríguez-Sala (Huelva: Universidad de Huelva, 1998), 46-49.

³⁸ Viceroy Antonio de Mendoza, an associate of the Council of the Indies, recorded his observations in 1541 of two lunar eclipses using an astrolabe and established the official coordinates for Mexico City in his Letter to chronicler Fernández de Oviedo dated 6 October 1541. Trabulse, *Ciencia y tecnología*, 31.

³⁹ The mariner's astrolabe was sparer in appearance and easier to use on board a ship. The Corpus Christi Museum of Science and History holds a mariner's astrolabe from the 1554 San Esteban shipwreck: <http://www.texasbeyonhistory.net/coast/images/wrecks-astrolabe.html>

would have used a terrestrial astrolabe which unlike the nautical version was based upon late medieval Arabic models.⁴⁰ Quadrants, used for calculating the altitude of an astronomical object or the distance between two, often took the shape of the quarter-part of a large circle with equally spaced markings up to ninety degrees.

Tools used during the course of the 1583 expedition included not only an astrolabe and a quadrant but also the revised tables of 1530s, as well as Herrera's newly designed device for confirming a longitude calculation.⁴¹ By then the Madrid Tables had replaced the famed Alfonsine Tables (ca. 1250) with Toledo, Spain as the prime meridian.⁴² The tables arranged mathematical computations into predictions about the location of astronomical bodies and the timing of eclipses. They also included catalogues of the known stars. A reliable method for determining longitude at sea was still two centuries to come (with John Harrison's marine chronometer of 1761), but determining latitude was accomplished by calculating the altitude of the sun at noon and adjusting that figure to the sun's declination for the day of the year as listed in the tables. Navigators also used the tables to estimate longitude through observations of lunar eclipses.

Upon arriving at the viceregal court in Mexico City in 1583, Juan would have seen Flemish astronomical instruments displayed in various libraries. The Frisius-Arsenius Astrolabe, taken to New Spain by its first viceroy the Marquis of Mondéjar and Count of Tendilla, Antonio de Mendoza (r.1535-1550), provides an example of the quality of astronomical tools imported to the viceregal court. This particular astrolabe, now at the Museo Nacional de Historia in Mexico City, is significant because, unusually, the artisan included his master's name in the inscription.⁴³ Mendoza was handy with the instrument and produced a highly accurate observation

⁴⁰ Roberto Moreno, Koenraad Van Cleempoel, and David King, "A Recently Discovered Sixteenth-Century Spanish Astrolabe," *Annals of Science* 59, no. 4 (2002): 333-44.

⁴¹ Rodríguez-Sala, "Eclipse," 47.

⁴² Tycho Brahe updated the Alphonsine Tables during the 1590s and his findings became, with assistance from Johannes Kepler, the Rudolphine Tables by 1602. By the first quarter of the seventeenth century, Fray Diego Rodríguez was already using Paris as the prime meridian for calculating the longitude of Mexico City. Towards the end of the seventeenth century Sigüenza y Góngora also determined the longitude of the capital. In the early eighteenth century, *criollo* José Antonio Alzate y Ramírez (1737-1799) determined the longitude of Mexico City with reasonable accuracy by using Jupiter's moons and Paris as the Prime Meridian. See Alexander von Humboldt, *Political Essay on the Kingdom of New Spain*, trans. J. Black (London: Longman-Brown, 1814), vol.1, xxvi.

⁴³ Van Cleempoel, *Catalogue Raisonné*, 335-36.

of the Lunar Eclipse on 16 November 1537.⁴⁴ The astrolabe is thought by some scholars to have been purchased for the viceroy's son.⁴⁵ It bears the arms of the Mendoza family, and the inscription reads: "DON FRANCISCO DE MENDOZA" with superscripts for the three "N" characters.⁴⁶

Other types of tools and *ingenios* (machines) contemporary with the expedition illustrate the types of inventions licensed by Philip II through the 1580s. They include: a variety of pumps for shifting water from ships, mines, and reservoirs; water desalination devices; ore extraction tools; mine lamps; tools for measuring altitude; compasses; a sunglass (a navigational instrument); new types of flour mills; metalworking devices; pearl fishing tools; diving bells; and other instruments useful for maritime archaeology.⁴⁷ These successful applications represent only a portion of the total number of instrument designs in circulation. Jaime Juan's astronomical research occurred in an American landscape that provided an outdoor laboratory to fuel technological innovation.

Well-known works of navigation probably accompanied Juan's expedition. Martín Fernández de Enciso's *Suma de Geografía* (1519) included a fold-out chart showing thirty-two sea roads and a compass rose displaying the predominant winds. Pedro de Medina's *Arte de Navegar* (1545) and the *Regimiento de la Navegación* (1563) detailed the latest techniques of navigation as did Martín Cortes' *Breve compendio de la esfera y del arte de navegar* (1551).⁴⁸ Available to a selected readership, which may well have included Juan, were planispheres which showed an early depiction of the disputed line of demarcation produced by the Casa de Contratación and gifted to Giovanni Salviati and Baldassare Castiglione by 1526, in addition to Alonso de Santa Cruz's ongoing consolidations of navigator's logs *Islario general de todas las islas del mundo* (written 1560) and *Libro de las longitudes*.

Books produced and printed in Mexico City between 1539 and 1590, the year of Juan's death in Manila, include more than a dozen known works on the physical

⁴⁴ Portuondo has compared his observed start time with data generated about historical eclipses by NASA to conclude that Mendoza's record is remarkably accurate; it differs by only one minute. Portuondo, "Lunar Eclipses," 250; *Secret Science*, 224.

⁴⁵ Miguel Fernández Villar, *Sobre el astrolabio firmado por Frisius y Arsenius* (México: INAH, 1976), 9.

⁴⁶ Van Cleempoel, *Catalogue Raisonné*, 34-37.

⁴⁷ AGI reference numbers cited in Appendix 2 of Barrera-Ororio, *Experiencing Nature*, 140-45.

⁴⁸ These titles are representative of the works Juan likely carried with him on his travels; an inventory of his books has not been found.

sciences. Alfonso de la Vera Cruz's *Recognitio, Sumularum* and *Dialectica Resolutio* were both published in 1554, and *Phisica Speculatio* appeared three years later in 1557. Juan Diez Freyle's *Sumario Compendioso* of 1556 is the earliest book of mathematics produced in the Americas.⁴⁹ Augustín de Vetancourt includes "De la longitude y latitute del Nuevo Mundo, Términos y Números de sus Leguas" as chapter 8 in his *Teatro mexicano: descripción breve de los sucesos ejemplares, históricos y religiosos del Nuevo Mundo Occidental de las Indias* which circulated in manuscript form prior to its printing. Francisco de Toledo's *Introductio in Dialecticam Aristotelis* and Francesco Maurolico's astronomical works *De Sphaera* and *Computus Ecclesiasticus* both came out in 1578. New editions of the Sicilian mathematician Francesco Maurolico's (1494-1575) works were printed in Mexico City in 1578. García de Palacios' *Dialogos militares* 1583 and *Instrucción Náutica* 1587 are well-known works on military instruments and navigation. Bartolomé de Medina's *El método de amalgamación de los minerales de plata* (1620) were written during his visit to New Spain's mines in the mid-1550s and 1560s and offer a snapshot of mining practices and technologies at mid-century. By 1585 Fray Bernardino de Sahagún had nearly completed the manuscripts for his *General History of the things of New Spain* during Juan's expedition. Book seven on "The Sun, Moon and Stars" was an account of native interpretations of European astronomy. The Sections in Book eleven "On Precious Stones," though less relevant to Jaime Juan's astronomical work, contributed to the local scientific community's knowledge for engineering and mining projects.⁵⁰

Jaime Juan and the Casa's *Instrucciones* for Observing Eclipses

The Casa de la Contratación directed all trade and traffic between Spain's overseas possessions and the Iberian Peninsula. More than just regulating the biannual fleets, the Casa trained pilots, collected charts for updating the Padron Real, and by the 1550s perpetuated a combined mathematical-and-practical approach to navigation.⁵¹ Communications for a long distance expedition depended upon the regular biannual transoceanic fleets. The structures of coordination required for such a

⁴⁹ Burdick gives an accessible introduction to this text in Bruce Stanley Burdick, *Mathematical Works Printed in the Americas 1554-1700* (Baltimore: Johns Hopkins University Press, 2009), 33-66.

⁵⁰ Navarro Brótons and Ibarra, *Bibliographia Physico-matematica*, vols 1-2 contains some of the works produced in New Spain that crossed the Atlantic during the early modern period.

⁵¹ Portuondo, *Secret Science*, 17.

project were separate from the bureaucracies already present within the colonies.⁵² As was the case in the Hernández Expedition (1570-1577), instead of relying upon the institutions already established in the colonial cities by government officials and religious orders, Jaime Juan's astronomical expedition took its instructions directly from the king. Juan also received advice from the royal cosmographer at the Casa de Contratación.⁵³

Scientists' freedom from local institutional interference, while giving them greater leeway in managing their time, money, and travels, increased their risks.⁵⁴ Moreover a letter from the king provided little protection from extortion and the physical dangers of long distance travel. For example, when Jaime Juan developed an illness that turned fatal, the best doctors were out of reach.⁵⁵ Likewise when Domínguez took on additional jobs, no local administrator reminded him that his exclusive contract to the king encompassed a set period of time.⁵⁶ The 1583-1590 expedition relied upon the scientists' desire to explore, observe, record, and report back.

Jaime Juan traveled west—by sea and overland—from the Canary Islands to Mexico City and then to Manila in order to take measurements of the “solar meridian” en route. According to the royal *cédula* detailing the assignment, he would travel to New Spain and the Philippine Islands and any other places where he might be sent, where he should make the following observations: in

⁵² Among the primary methods of long-distance communication was a public postal service: the Correo Mayor de las Indias. As a branch of the Spanish Post (Correo Mayor de España) the Correo de las Indias was established in 1514 and held a monopoly on all post from, and between, the provinces. For the Real Cédula of employment to Galíndez de Carvajal as the first director of the “Indies Post” in Seville see: “Título a Lorenzo Galíndez de Carvajal como director del Correo de Indias,” (Patronato, 170, R.18). The postal service transported personal letters across the Atlantic from an early date as demonstrated by Enrique Otte's findings at the Archivo de Indias. Otte transcribed more than 630 letters from ordinary Spanish settlers in the Americas to their families on the Iberian Peninsula dated between 1540 and 1616; typical comments from settlers in New Spain include remarks about the temperate climate, fertility of the land, and abundance of food sources in contrast to the contemporaneous famines of Spain. See Enrique Otte, *Cartas privadas de emigrantes a Indias, 1540-1616* (México: FCE, 1993), 21-22.

Also see Vicent Salavert Fabiani, “La imprenta y la difusión y comunicación científica de los saberes y las técnicas (1561-1600),” in *Felipe II, la ciencia y la técnica* (Madrid: Editorial Actas, 1999), 255; 60-62; José Vallejo García-Hevia, “El Correo Mayor de las Indias (1514-1768)” (paper presented at the Derecho y administración pública en las Indias hispánicas: XII Congreso Internacional de Historia del Derecho Indiano, Cuenca, 18-21 October 1998), 1785ff.

⁵³ María Luisa Rodríguez-Sala, “La Observación del Eclipse de Luna del 17 de noviembre de 1584,” in *El Eclipse de Luna: Misión Científica de Felipe II en Nueva España*, ed. María Luisa Rodríguez-Sala (Huelva: Universidad de Huelva, 1998), 27.

⁵⁴ With freedom came a degree of uncertainty, and accessing their salaries was at times difficult.

⁵⁵ Rodríguez-Sala, *Eclipse*, 43ff.

⁵⁶ “Francisco Domínguez y Ocampo, Geógrafo y Cosmógrafo,” 69-70.

the case of disembarking at any islands on the way to Veracruz, he should identify the meridian of that place using the instruments that he has by measuring, precisely, the angle northwest or northeast—in degrees and minutes—that the closed needle makes with the magnetic stone. He can make the measurements with the aid of an instrument or rounded ruler as well as the tables of sines and arcs which he has with him. After having done so, he should note his calculations in a separate book where he should also note the name of the island, the specific place name, and the date...⁵⁷

On the following day Juan should use the stone tile—which he is to always carry with him for placing his viewing instruments upon—for a second set of measurements. According to his royal instructions, when the sun was at its noon meridian, Juan should measure its greatest height and then add or subtract the sun's declination for that day according to the "rules known for that purpose." The resulting figure would then be the "height of the equinoctial over the horizon at that particular location," and once taken from ninety degrees would indicate the "height of the pole," which he could then compare with the observations made using a magnetic compass—and note any differences in the resulting calculations—for a reliable set of coordinates defined in the Caribbean, Veracruz, Mexico City, Navidad, and the Philippines.⁵⁸

Further stipulations indicated that Juan should observe any eclipses that may take place, be wary of potential interference upon the magnetic compass from local iron deposits, and he should also teach. This job required that he spread better celestial navigation techniques by noticing where the navigators' calculations were correct or in error, and unobtrusively show them how to improve their accuracy — either by using different algorithms or making better use of their instruments.⁵⁹ The teaching aspect of his duties addressed what the cosmographers major of the Casa believed was a 'reluctance to change' from the majority of seagoing pilots.⁶⁰

⁵⁷ AGI, Indiferente, 740. N. 103. Transcribed in "Eclipse," 46.

⁵⁸ AGI, Indiferente, 740. N. 103. Transcribed in *ibid.*, 47.

⁵⁹ There is a subtlety about Juan's role as a teacher; the text implies that he is expected to share better practices with the navigators without drawing much attention to himself as an expert. This tactful approach would presumably keep relations cordial between the royal astronomer and the ships' pilots: "Jaime Juan should look carefully at what the said pilots and mariners use in their navigations so that by their operations he may see where they are correct and where mistaken, in order to help them to understand the truth [utility] of certain procedures." AGI, Indiferente, 740. N. 103. Transcribed in *ibid.*, 48.

⁶⁰ This reluctance, if it was characteristic of pilot culture, may have had to do with literacy rates among galleon crews and the experiential bias of sailing crew culture—learning by doing would have been a mandatory feature of living aboard a ship. Pérez-Mallaína notes that 100% of high officers, 74% of pilots, 55% of gunners, and 22% of sailors were able to sign their own names. Signatures are taken as evidence of some literacy, and the figures for high officers is most reliable as they were

Cartography was another aspect of his role as lead astronomer on the expedition. Whether he should oversee the production of maps of the places he had visited or draw them himself is not stated, but as he did not meet his vicereally appointed cartographer until he arrived in Mexico City, he likely limned the coordinates of his Atlantic stopovers himself. Finally, he should collect—from governors and viceroys along the way—copies of the best maps available of the provinces he visited.

Philip submitted, as was his custom, his royal decree for the expedition to the Council of the Indies for their approval and contributions.⁶¹ Finding them bogged down in the details and potential costs of the campaign, however, Herrera motioned the Council to make their amendments quickly as the outbound fleet would soon sail. The Council responded just in time and added a few more tasks to Juan's *Instrucciones*. According to the king's *cédula* of 5 May 1583 written at the royal residence in Aranjuez, Juan's salary was 400 ducats a year for eight years payable by the viceroy of New Spain and the Philippines.⁶²

Juan embarked in June of 1583 with Captain Gabriel de Ribera and traveled in the admiral's flagship. Weather delays kept the fleet at port until October. They anchored in the Canary Islands, Cuba, and Puerto Rico where they calculated the latitude and longitude. Juan also made observations at sea on his way to New Spain.

The Report of the Lunar Eclipse Observation

During his stay in Mexico City Juan was hosted by Viceroy Villanueva y Zapata at the royal palace and mingled with the government elites and men of science resident in the capital. Clergymen trained in mathematics and astronomy, frequently

aristocrats who regularly produced official documents; see, Pablo Pérez-Mallaína, *Spain's Men of the Sea: Daily life on the Indies fleets in the Sixteenth Century*, trans. Carla Rahn Phillips (Baltimore: Johns Hopkins University Press, 1998), 231, table 6.1. An interesting counterpart to this middling literacy of the ships' crews was the high degree of literacy of the passengers. In order to obtain passage on a transoceanic vessel, the Spanish Crown required the completion of an application process which excluded persons without the means to sustain a case for travel or migration. Theatre and performative readings of books of chivalry, such as *Orlando Furioso* and Golden Age theatre, were common and enjoyed a wide audience on transoceanic journeys; see, *ibid.*, 159-63; Irving Leonard, *Books of the Brave: Being an Account of Books and of Men in the Spanish Conquest and Settlement of the Sixteenth-Century New World* (New York: Gordian Press, 1964 [1949]), 42; *Colonial Travelers in Latin America* (New York: Juan de la Cuesta, 1972), 25.

⁶¹ Portuondo, *Secret Science*, 60ff.

⁶² The Consejo de Indias granted Juan an advance of 100 ducats in preparation for the voyage and all subsequent payments were made by the royal treasury (*real hacienda*) in Mexico City. AGI., Contratación 5788, L.1, f.176v-177 del 5 de mayo de 1583, Cédula real de 'Situación de salario a Jaime Juan'; transcribed in Rodríguez-Sala, "Eclipse," 44-45.

belonging to one of the missionary orders, were regular participants in the city's intellectual life. Pedro García Farfán (ca 1532-1604), who changed his name to Agustín Farfán upon entering the Augustinian order in 1569, was one of the city's best known physicians because of his *Tratado breve de anathomia y chirugia* (1579) and assisted in Juan's observations of the lunar eclipse of 1584.⁶³ In New Spain the degree to which training in mathematics coincided with a clerical profession was high; training for clerical offices required advanced schooling, and a significant proportion of colonists authorized by the king to settle were members of religious orders.⁶⁴

As an additional component of the *relaciones geográficas*, Casa cosmographer López de Velasco (c.1530-1598) wrote the *Instrucciones* of 1582 for recording eclipse observations. The instructions were intended for people without astronomical training,⁶⁵ detailing how to use a pole of a specified length upon a level surface and make specified measurements and drawings in order to identify a location's coordinates.⁶⁶ The original texts as well as the translation by Edwards are consciously unadorned:

One or two days before the eclipse, in an open and exposed spot on which the sun shines at rising and setting, construct a plane surface with a ruler and level, at least a yard [vara: about 83.8 centimetres] square...draw two circles in the middle, one within the other with a common center...Once these circles are drawn, drive into the center point a nail or stile of iron or wood. It must be straight, smooth, and thin, and exactly one-third yard long, not counting the part driven into the plane surface. It must be vertical....

This done, after sunrise watch carefully for the direction and point along the circumference of the larger circle at which the shadow of the stile is entirely enclosed in it, and at the precise time that the tip of the shadow touches the circumference, neither inside nor outside, but right on it, make a mark on the line in the centre of the tip of the shadow. Then do the same for the smaller circle, when the shadow enters it....

⁶³ His second medical work, *Tractado breve de medicina* (1592), is notable for the large number of its indigenous remedies and was likely influenced by Francisco Hernández's investigations fifteen years prior.

⁶⁴ For those who were mathematically inclined the career as priest offered more than room, board, and social esteem. Even to men from modest backgrounds, joining the clergy provided distinct career benefits such as membership in a climbable hierarchy as well as daily practice in the skills of rhetoric and diplomacy—essential to any political advancement.

⁶⁵ Clinton notes the "simple language" used in the *relación* surveys, Portuondo states that the instructions for the lunar eclipse observations could be understood by even the "curious novice," and I have found a comparable clarity in Juan's itinerary. The authors of these three texts appear to have had pedagogical motives and valued accessibility to the non-specialist reader.

⁶⁶ Portuondo, "Lunar Eclipses," 257ff.

Before the day of the eclipse, make an instrument in the following form, which will be simple to do... Allowing sufficient time on the day of the eclipse, place this instrument on edge over the platform on which the shadow was measured, facing the side opposite that on which the noon shadow fell. If the shadow fell toward the north, the instrument should face south, or if the shadow fell to the south, the instrument should face north...

In the evening, when the full moon starts to rise in the east, have a number of people observe whether the moon rises perfectly round, as it will if it is not eclipsed upon rising, or whether it appears lopsided on some part of its roundness, or totally obscured...

The drawing on paper should in all respects represent precisely the figures observed on the instrument. Make a duplicate, and another of the paper showing the measurements of the stile and shadow for noon. Along with the names of the people who made the observations, send each duplicate separately to his Majesty, in care of the Royal Council of the Indies. Even if because of cloudiness or other hindrance the eclipse cannot be observed, measure the length of the noon shadow on that day, or on another on which it can be done.

Send this measurement and that of the stile, as directed above, with a report of the day, month, and year when it was taken. Report any reason for not being able to take it on the day of the eclipse.⁶⁷

The text concretely explains how to measure and record the lengths of particular shadows at specified times. These figures can then be used to determine the longitude of a site.⁶⁸ A rod of approximately one metre in length was placed at the centre (*punto fijo*) of two concentric circles. Preparations began two days before the forecasted eclipse and preliminary observations were made. All final measurements were drawn on a large sheet of paper (and its duplicate) illustrating where the noonday sun's shadow fell on the circles.⁶⁹

⁶⁷ Edwards, "Mapping by Questionnaire," 20-21. My emphasis.

⁶⁸ Determining longitude at sea is more difficult because of the constant movement of a ship and the earth's east-west rotation. In 1598 Philip III offered a financial reward (6,000 ducats)—renewed from Philip II's offer in 1567 to any scientist who could resolve the difficulties of finding longitude at sea. From 1612 to 1617 Galileo designed his method and an instrument he named the "celatone" for observing Jupiter's moons from a ship's deck. The device consisted of a helmet with a telescope attached to the eyeslit; the wearer would be seated within a small, watertight tub within a pool of fluid on the deck of a ship. The movement of the ocean would theoretically be corrected by the fluid upon which the wearer's tub floated and thus the wearer's movement relative to the moons of Jupiter would be stabilized from the rocking of the ship. Galileo's trial runs were unsuccessful but his method of observing Jupiter's moons as a celestial clock was posthumously used on land. See, Víctor Navarro Brotóns, "Galileo y España," *Largo campo di filosofare: Eurosymposium Galileo* (2001): 811ff.

⁶⁹ By ca.1610 when the celebrated novelist, Miguel de Cervantes (1547-1615), wrote his short stories, *Novelas Ejemplares* and the lyric poem *Viaje al Parnaso* (page 127 of the 1786 edition), the

The observation of the forecasted lunar eclipse took place on the rooftop terrace of the viceregal palace on 17 November 1584 and ended at 7:27 by “a very precise pendulum clock.”⁷⁰ Gudiel, the royal armourer, took the role of positioning the implements for taking measurements and was the third official member of the expedition. By their own accounts Cristóbal Gudiel and Francisco Domínguez (ff.4v-5r, 5v-6r) each drew their own figures, referred to as “el instrumento” by Juan, made up of concentric circles with a gnomon at its centre on the day before the eclipse. Their documentary reproductions of these instruments show the same lengths but a slightly different angle for the shortest shadow at midday; they may have drawn separate “instrumentos” on the same rooftop or worked on separate rooftop terraces.⁷¹

Jaime Juan’s report with Domínguez, Gudiel, and Farfán, the “Juizio Astrológico del eclipse de la luna que aconteció en 17 de noviembre Anno 1584” includes an astrological prologue (in Spanish), eight annotated diagrams, and a seven-part explanatory report. To aid its readers, the first section of the explanatory report is written in Spanish as an introduction to the other six sections written in Latin. The selective use of two languages indicates how Spanish scientists sought to make their findings accessible and skimmable while also authorising it with the lingua franca of scientists in Europe. Sections two through seven are technical records of the astronomers’ mathematical calculations; they include additional diagrams—two geometric and one schematic. The expedition sought a notable degree of accuracy and reliability. Juan, Gudiel, Domínguez, and Farfán each produced and submitted their own drawings, contributing to the collective observation of the eclipse.

phrase “punto fijo” had already come into common parlance in Spain. His phrase refers to the calculation of a site’s fixed coordinates, and more broadly, the truth of a matter. In the “Casamiento engañoso y diálogo de los perros” one of his characters is a mathematician who has dedicated his life to measuring coordinates. The mathematician discusses with an interlocutor a project of measuring coordinates that “has been going on for twenty-two years.” The fictionalized reference coincides with expeditions such as Juan’s from the same period. Miguel Cervantes Saavedra and Harry Sieber, *Novelas ejemplares, II* (Madrid: Cátedra, 2007), 356.

⁷⁰ Gudiel’s annotated diagram of the instrument and observation identifies the physical site as the rooftop terrace of the viceregal palaces (*las casas reales*) in Mexico City (ff.2v-3r), and he also noted the use of a particular type of weighted clock: “un relox de pesas muy preciso que estaba puesto para el mismo efeto” (ff. 3v-4r).

⁷¹ The archbishop and Galenist doctor, Augustín Farfán (ca. 1532-1604), identified his own rooftop as the site for his observation (ff.6v-7r, 7v-8r). It seems that two observations were held simultaneously on different terraces of the ‘casas reales.’ Juan states on his drawing of the instrumento, that the eclipse ended at 7:31pm (ff.9v-10r). During the viceregal period, the archbishop’s residence was literally a stone’s throw away, across Calle Moneda, from the viceregal palace. The location of these historic ‘casas reales’ today is the heart of the city adjacent to the cathedral and the museum of the Templo Mayor.

The first section of Juan's report outlines the team's adherence to the *Instrucciones*.⁷²

Observation of the lunar eclipse that took place 17 November 1584 in Mexico City (metropolis of New Spain) at 7 hours 22 minutes 8 seconds after midday, by which a difference of longitude and distance from Mexico City and Sevilla was measured.

First Proposition:

Three methods were used for knowing the end time of this eclipse. The first and most important was the one His Majesty issued [the *Instrucciones*] which follows below:

Firstly, on 17 November of the said year, upon a very flat plane...we planted a stake measuring one third of a castillian vara posted at a right angle to the said horizontal surface. And by the least shadow that the stile made, the sun being on this day at its height (meridiana) when it casts the smallest shadows, we found the shadow of the gnomon at 47 parts 30 minutes out of 60 parts, and drew this line. Having found the meridian, we drew a perpendicular line to cut it in half, creating right angles, and this one which bisected the meridian line represented the line of sunrise and sunset (veri ortus et occasus). Along this line of sunrise and sunset we set up a plank, one vara in length, and just over one third of a vara in width. With the plank [centred at the stile] we drew a semicircle... Night came and the plank was positioned on the line of veri ortus et occasus in the said manner (with one end pointing to the midday mark and the other towards North). The moon rose from the horizon completely eclipsed and so we were not able to pinpoint the start time of the eclipse; we waited until the eclipse cleared and the moon was at its perfectly round fullness at which point we noted upon the semicircle where the moon caused the stile's shadow to fall. It was at 24 degrees 45 minutes from the line representing the sixth hour of the morning on vertical astronomical clocks for the northern hemisphere against the perpendicular which represented the 12 hour clock. At the same time as that was happening, we noted on a geared clock showing hours and minutes, the most synchronized as possible, that it was 31 minutes after 7 o'clock in the evening.

In addition to the hour observed with the geared clock, we found through the height of the moon and the elevation of a fixed star, how many hours had passed since midday precisely, as will be shown in the following six propositions.

The first through third sections of Juan's report (Table 2.3) demonstrate that he used the Casa's method for producing the observation results and then checked the

⁷² My translation of Rodríguez-Sala's transcription in *Eclipse* p.152: AGI, Patronato 183, N.1, R.13 (Mapas y Planos México-34) ff.11r-f.14r.

calculations against an alternate method of his own. Section Four discusses the results that he obtained using each of the methods.

Table 2.3: Jaime Juan's Report – The Seven Propositions (1584)

Proposition One: The method prescribed by the Casa de Contratación.

Proposition Two: Using the apparent height of the moon of 24 degrees 45 minutes upon the meridian line to find how many hours after midday the eclipse took place.

Proposition Three: Using fixed stars to ascertain the time of the Hourly Arc.

Proposition Four: An explanation of the 1'48" discrepancy between the results described in first and third propositions.

Proposition Five: A brief explanation of those things that have been said about parallax.

Proposition Six: A brief demonstration of those things that have been deduced for finding the difference of time between midday and the observation.

Proposition Seven: Calculation of how by way of "spherical triangles" (*triángulos esféricos*) the difference of longitude and latitude can be found.

Source: *Eclipse* p. 152-58: AGI, Patronato 183, N.1, R.13 (Mapas y Planos México-34) ff.11r-f.14r.

Jaime Juan's report illustrates how the *Instrucciones* described only one of the methods available to astronomers at the time and how an extremely simple "instrument" was made from a stile, a plank, and a stick for drawing on the ground. The records sent to the Casa reproduce the lines drawn upon the ground, the location of the stile, and the placement of the plank. In his report, Juan refers to the drawings upon the ground as an "instrumento" which suggests an interesting usage of the term; in this context "instruments" encompassed more than material artifices and graduated metal tools, for example, astrolabes. The instruments in this astronomical observation included some items as basic as drawings of concentric circles on level ground. Part of the reason for resorting to such universally available "instruments" is the desire of the Casa to create a common, standard reference point for all of the reports that they would receive: if only some responses were produced using specialized equipment, the discrepancies between those with and those without would likely have produced inconsistencies and further unknown variables. The Casa sought as far as possible to use the data received from its overseas respondents to create an official map of Spanish possessions.

After participating in this expedition Juan travelled to Acapulco and when he arrived in Manila the local governor, Gonzalo Ronquillo de Peñalossa, showed him duplicates of the longitude measurements and maps produced by the Augustinian Martín de Rada (1533-1578) twenty years earlier. Juan contracted an illness and died of fevers, probably malaria, in Manila. His manuscripts on the Philippines, now lost, are thought to have inspired further expeditions undertaken by Nicolás de Cardona and others (c.1618-1623) to outline New Spain's northernmost ports on the Pacific.⁷³

The Expedition's Cartographer: Francisco Domínguez y Ocampo

Between 1584 and 1589, in Mexico City, Juan had met first with Francisco Domínguez y Ocampo, his official cartographer on the expedition. Domínguez, as we saw in chapter one, had already served for a short time with the botanical expedition of Francisco Hernández as the royal *geógrafo*. After leaving Hernández's expedition he had been employed by the viceroy as a cosmographer and consultant on the capital's water drainage project. His appointment as cartographer for Juan's expedition indicates his success in maintaining an active profile upon which the Crown could rely. He lists an impressive degree of engagement with cartography in New Spain. Not only did he make topographical maps of various cities—between 1571 and 1574 he mapped twenty-two provinces of New Spain—he also trained ships' pilots, built navigational instruments, and mapped the early explorations undertaken by Baltasar de Obregón in New Mexico.⁷⁴ His most notable accomplishment by far was his map of China (c. 1580) based upon the data in circulation within New Spain.

Among the documents found at the Archivo General de la Nación (Mexico City) by Rodríguez-Sala in the late 1990s was a picture of the Hernández expedition (Chapter 1) from Domínguez's perspective. Until now the botanical expedition had been written about as if the expedition's cartographer had dropped out permanently but Domínguez rejoined the group after an interval. The documents by Domínguez

⁷³ A century later during Peter the Great of Russia's reign, these northernmost ports became politically significant in a Spanish Bourbon - Russian contest to inhabit northern California and what is now Washington State. León-Portilla, *Cartografía*, 97ff.

⁷⁴ Baltasar de Obregón (1544-post 1584) arrived in Mexico City in 1570 after a seven year overland expedition to California at first with Antonio de Luna and later with Francisco de Ibarra to New Mexico. Obregón wrote his account of the journey as "Historia de los Descubrimientos Antiguos y Modernos de la Nueva España" and is thought by scholars to have provided the data upon which Domínguez made maps of New Mexico some years before the Crown approved its colonization in 1584.

also demonstrate the variety of scientific endeavours taking place under the purview of the viceroy in New Spain, and his central involvement in the scientific community of Mexico City.

One of these documents was a letter Domínguez wrote in 1584 to inform the king of his ongoing commitment to the Crown's projects—"Información de servicios y méritos." Here he requested a title of cosmographer of New Spain and the Philippines to enable him to "examine pilots in the Southern Ocean ... according to His Majesty's ordinances in order to remove many difficulties that come from leaving this task with persons who have little expertise in this field."⁷⁵ From the sound of his request, Domínguez intended to make himself the director of something equivalent to the *Casa* in Seville, located on the Pacific Coast of New Spain. Though he does not suggest an exact location, a port such as Navidad, which was already in use for transporting goods from Peru to Seville (via Mexico City and Veracruz), may have been what he had in mind. Another possible site, Acapulco, became New Spain's fully fortified Pacific port by the end of the seventeenth century and held a naval artillery training school by 1678.⁷⁶

In this 1584 letter, Domínguez y Ocampo also explains to King Philip II why, although he spent five years mapping the district under the Audiencia of Mexico City, he had not completed his original task of mapping all of New Spain on the Hernández expedition a decade earlier. As he stated:

I understand Your Majesty that your royally mandated voyage through these parts by doctor Francisco Hernández, royal protomédico, is present in your royal memory. And that in addition to the specimens which Hernández collected, his task of describing the properties—both theoretical and practical—and virtues of the herbs and plants. Beyond his duties, was my duty to describe the lands of New Spain in terms of the coordinates of the globe, as Ptolemy did in his time for all the eastern regions of the world, by his own account. Being elected by your royal decree I have served for five years in this role during which I have completed the area under the jurisdiction of the Royal Audiencia of Mexico.... Philip II is, like Ptolemy, the first to map the

⁷⁵ "Información de los Méritos y Servicios de Francisco Domínguez 1594." AGI., Patronato, 22, R. 11, 261, R.9; transcribed in "La Carta" José Toribio Medina, *Biblioteca hispano-americana* (Santiago de Chile: Medina, 1900), 297.

⁷⁶ The port at Acapulco was granted a royal monopoly to the Manila Galleon trade in 1573. Acapulco's fortification included designs by engineers of international repute such as Adrian Boot during the late 1630s and the captain of the German infantry and military engineer Jaime Franck ca.1687-1693. Calderón Quijano, "Ingenieros militares," 10-12; *Nueva cartografía de los puertos de Acapulco, Campeche y Veracruz* (Sevilla: Escuela de Estudios Hispanoamericanos, 1969), 4-5.

New World...What is done is left imperfect as a work that had a beginning and lacks an end.⁷⁷

With great tact, Domínguez y Ocampo admits to stopping his work on the king's project in 1575 and moving on to other cosmographic activities commissioned by the Viceroy Martín Enríquez, the Conde de la Coruña (1568-1580), and the Archbishop-viceroy, Pedro Moya de Contreras (1584-1585). His decision to move on to a local and more secure funding displays his acumen and desire to remain in New Spain. The letter makes a subtle plea for his unpaid salaries; he refers to past salaries as a "closure which is lacking" from the Hernández expedition. Philip II reluctantly instructed the viceroy to pay Domínguez for all of his work. The viceroys shared responsibility for paying Domínguez's salary, but as Philip initiated the expeditions and the system of judicial appeals within the Spanish empire ultimately led to the king, it is little wonder that he petitioned the Crown directly.

Domínguez's participation in the scientific activities of New Spain was significant. The nature of his textual/visual production would suggest that his works are yet to be found among the sixteenth-century map collections of Mexico City. Until more of Domínguez's writings and charts have been identified, his Last Will and Testament is among the best sources to document his professional activities. His narrative indicates that he participated in at least five different realms of scientific activity while based in Mexico City: (1) training pilots, (2) creating maps for the viceroy based on explorers' reports, (3) teaching cartography (4) assisting on the Hernández botanical expedition during the 1570s, and (5) assisting Jaime Juan's astronomical expedition in the late 1580s.⁷⁸ In his last decade he also supported the medical work of the Hospital de San Hipólito y Convalecientes.

Domínguez describes in his will's prologue a vibrant, scientific community in the New World. Mexico City with its viceregal court had, since the arrival of the Spanish sixty years earlier, accumulated the types of financial resources, scientific instruments, and intellectual networks necessary for European scientists and mathematicians to conduct a series of experiments across two oceans. With Domínguez y Ocampo's broad-ranging efforts to consolidate and train pilots—and others—in the techniques of cartography and navigation, we see the laying of a fertile

⁷⁷ "La Carta de Domínguez al rey," Toribio Medina, *Biblioteca hispano-americana*, 294-97.

⁷⁸ Domínguez also indicates that the viceroy assigned him to update the "tablas" by which he must mean charts: "And not satisfied, the viceroy requested that I update the *tablas* like those that Hernández took Your Majesty but better adjusted." Ibid.

ground for the mathematical sciences which will later become the salons (*tertulias*) of Diego Rodríguez and Sigüenza y Góngora's progressive ideas about astronomical observation. New Spain offered the technically-trained, early modern *científico* the type of novel and challenging work environment that appealed to ambitious temperaments.

Scientists in New Spain could call upon the backing of local patronage from the viceroy in addition to the Crown in Spain. The first viceroy of New Spain, Mendoza, was an avid astronomer who trained his son to use the fine Belgian astrolabe he had brought from Europe. A set of astronomical and nautical skills may have aided one's appointment for the position of viceroy.⁷⁹ Like the Crown in Spain, the viceroy needed to combine robustness, political savvy and intellectual curiosity. Unlike the Crown, the viceroy held an appointed position. He needed to be capable of crossing an ocean and governing unknown territories with a diverse population without succumbing to illness or assassination. It makes sense for a viceroy to have maintained close ties with his cosmographers and to have engaged directly with scientific observation on a regular basis. Antonio Barrera-Osorio has demonstrated how the viceregal court "became the place for performing [product] 'tests' in the New World."⁸⁰ Indeed, the viceregal court in Mexico City had invested in potential commodities, such as dyes and foodstuffs and supported the work of productive scientists in the capital.

Conclusion

In a colonial context, expertise tends to be a limited commodity as the large-scale production of technical instruments and the local education of technicians takes decades to establish. Nevertheless in New Spain a significant number of the sixteenth-century Europeans who traveled and settled there were endorsed by Philip II precisely because of their skills and training. Scientists Jaime Juan and Francisco Domínguez y Ocampo provide evidence of a skilled network of individuals extending from the viceregal court in Mexico City. Educational institutions like the Real y Pontificia Universidad de México (1551), as well as informal institutions founded by Jesuits and Mercedarians, made training in mathematics increasingly available to a diverse population. Likewise, the craft production of scientific instruments in Mexico City

⁷⁹ Rivero Rodríguez, *Edad de oro*, 82-85; 89-96.

⁸⁰ Barrera-Osorio, *Experiencing Nature*, 27n.71.

often accompanied a thorough training in applied mathematics because at times it was more efficient to build an instrument than wait for it to be imported from Europe. Expertise was then limited to those individuals who were able to craft their own instruments or order bespoke pieces via transatlantic networks. Early institutions such as the glassworks of Puebla (1539) and the native-operated printing press at the Colegio de Tlatelolco (1540) included training in local manufactures, while imports of astrolabes, and later telescopes, from European production centres like Leuven filled out instrument supplies in the New World. By the end of the sixteenth century in New Spain metalwork and stonework were well established industries that provided some of the components for locally built scientific tools.

The Crown's scientific expeditions bore many fruits. Cartography and astronomy in New Spain made much needed visual data available to the Council of the Indies via the Casa's cosmological projects. Philip II and his advisors, then, could assess these consolidated figures and charts for the economic potential of natural resources. This chapter has identified the nascent scientific community in New Spain from Philip II's sixteenth century scientific expeditions. Spanish tools, practices, and other institutional supports were essential to the promotion of mathematical approaches to science in the Americas. Over the course of the seventeenth century, as we shall examine later, indigenous astronomy was claimed by creole scientists in Mexico City in order to distinguish, politically, novohispanic science from Spanish imperial claims. During Philip II's, reign however, indigenous science still represented a threatening otherness which limited its circulation.

After Alexander von Humboldt's trip to record the geographical features of New Spain in the early nineteenth century, he wrote that the new continents had provided European immigrants with a consequential impetus to progress in the mathematical and physical sciences.⁸¹ Elías Trabulse has taken Humboldt's point further to see in the encounter of Spanish engineering technologies with the indigenous empires of the Americas a proving ground for the concepts, skills, and instruments of the multi-sited Scientific Revolutions. During an age of the first truly global economies, the scientific and technological advances of the different continents spread through commercial, religious, and political networks. The following chapters

⁸¹ Trabulse, *Ciencia y tecnología*, 9.

will further discuss the movement of instruments, experts, and their books into New Spain and from there back to Europe and parts of East Asia.

Chapter 3 A Culture of Debate and Publication among Mexico

City's Hydraulic Engineers (1606-1640)

A glittering island city met the Spanish as they marched from the mountains towards the capital of the Aztec Triple Alliance 1519. A soldier in Hernán Cortés' crew, Bernal Díaz del Castillo recalled at the age of seventy (c. 1568):

When we saw all those cities and villages built in the water, and other great towns on dry land, and that straight and level causeway leading to Tenochtitlan, we were astounded. These great towns... and buildings rising from the water, all made of stone, seemed like an enchanted vision from the tale of Amadís. Indeed, some of our soldiers asked whether it was not all a dream.¹

As a much younger man, Hernán Cortés reported in his second letter to Charles V in 1519 a more pragmatic, if still oblique, depiction of Nahua hydrology. He noted the masonry aqueducts mounted five feet high on one of the city's causeways, composed of two parallel channels, "two paces wide." While the first channel is in use, "the other is empty; it is used when they wish to clean the first channel." To avoid contamination from the salt water lake below, certain bridges have canal-like reservoirs. "The whole city is thus served with water," Cortés wrote, "which they carry in canoes through all the streets for sale, taking it from the aqueduct."² Early

¹ Bernal Díaz del Castillo, *The Conquest of New Spain*, trans. John Cohen (Baltimore: Penguin, 1965), 214. The *Amadís de Gaula* (Zaragoza, 1508) by Garci Rodríguez de Montalvo was one of the most successful publications of chivalric romance on the Iberian Peninsula during the sixteenth century. Soldiers and sailors alike carried chivalric romances with them on their voyages to the Americas. See Leonard, *Books of the Brave*, 43. In works of this popular genre, knights battled fantastic opponents in paradisiacal landscapes, hence the comparison with Tenochtitlan.

² Hernán Cortés, *Hernán Cortés: Letters from Mexico*, eds. Anthony Pagden, et al. (New Haven: Yale University Press, 1986), 107-08. During the viceregal period, Tembleque's Aqueduct was built in the arid region just north of the Valley of Mexico from 1553 to 1570 and is a good example of early hydraulic engineering projects that exhibited the technical skills of architects and builders residing in New Spain. Forty-two kilometres of a Roman style arcade, the aqueduct carried water from the springs of the Tecajete Volcano to multiple towns from Zempoala to Otumba. At its highest from the ground the aqueduct rises a notable 38.71 metres. See Octaviano Valdés, *El padre Tembleque* (Mexico: Editorial Jus, 1961), 12ff; Horacio Ramírez de Alba, "Los acueductos de Zempoala y Xalpa: sitios históricos de la ingeniería civil," *Ciencia Ergo-Sum* 2, no. 3 (1995): 339-44. Scholar María Castañeda has recently published transcriptions of the Tembleque Aqueduct records in *En busca de agua para no morir de sed* (México, UNAM, 2015). Seventeenth-century aqueducts within the city included those of Tlaxpana-San Cosme and Chapultepec-Belén; see Francisco de la Maza and Luis Ortiz Macedo, *Plano de la Ciudad de México de Pedro de Arrieta, 1737* (México: UNAM, 2008), 199-

accounts of Tenochtitlan-Mexico City provide evocative descriptions of straight streets, fragrant open air markets and beautiful “floating” flower fields, *chinampas*. Rising out of the lakes at the lowest point of a bowl-shaped valley encircled by mountains—a sight like no other—Tenochtitlan fit the conquistadors’ idea of a worthy seat of government.

Nearly a century later Bernardo de Balbuena, in his 1604 encomium to the baroque city he had known as a university student,³ highlighted the view of roads rising out of the water: “This grand city above water made / holds broad causeways, which for its multitude of inhabitants are too narrow.”⁴ The poet also described the canals by which the “crystalline” lake waters meander through a truly amphibious city.⁵ And yet, what is not apparent here is that a conceptual change had taken place:

204. Fifteen other early colonial era aqueducts in the Valley of Mexico are discussed in Manuel Romero de Terreros and Justino Fernández, *Los acueductos de México en la historia y en el arte* (México: UNAM, 1949), 35ff.

³ Bernardo de Balbuena—who stayed in Mexico City (1584-160[4]) during his twenties between growing up in Spain, crossing the Atlantic at least three times, and administering a post in the Caribbean—describes the abundance of the meats, fruits, and treats available in the city in the late 16th century. Bernardo Balbuena, *Grandeza mexicana*, ed. Asima Saad Maura (Madrid: Cátedra, 2011), 206. His comments are comparable to those included in Bernal Díaz’s *History of the Conquest* 214, 225-227. Both men seem to have been struck by the local flowers, orchards, and gardens (Balbuena 232, 237; Bernal Díaz, 215). Florentine merchant Francesco Carletti visited Mexico City in 1596 and also spoke well of it: “The City of Mexico is an earthly paradise, full of every good thing and all sorts of delights. It enjoys everything that comes from Spain, from China, and from other provinces of those lands, and it is populated by many more Spaniards than live in Lima.” Francesco Carletti, *My Voyage around the World*, trans. Herbert Weinstock (New York: Pantheon Books, 1964 [1594]), 66-67. The colonial city’s surrounding regions, such as Cortés’ lands, the Marquesado, were also notable for their landscape and productive mix of local and Spanish agriculture as Durán (1537–1588) states: “There are delightful springs, abundant rivers full of fish, the freshest of woods, **and orchards of many kinds of fruit, many of them native to Mexico and others to Spain, which supply all neighboring cities with this fruit.** It is full of a thousand fragrant flowers and is very rich in cotton.” Fray Diego Durán, *The History of the Indies of New Spain*, trans. Doris Heyden (Norman: University of Oklahoma Press, 1994), 15. My emphasis.

⁴ Balbuena, *Grandeza*, 169. Balbuena’s poem, printed in Mexico City in 1604, depicts a baroque city of public theatre and poetry competitions, triumphal arches made for elaborate holiday parades, and elegant private libraries. The poem describes the perks of being a university student in the viceregal capital: “gatherings, soirees, enjoyable concerts, performances, diversions and socials...parties and theatre, new plays every day...entertainment and pleasures,” (203). Balbuena’s sense of the city’s centrality in a global arena is also evident: “In you [Mexico City] Spain meets China, Italy meets Japan, and an entire world comes together in commerce and order,” (205). A prose eye-witness account of public celebrations in the capital can be found in Antonio de Robles, *Diario de sucesos notables (1665-1703)*, ed. Antonio Castro Leal, 2nd ed., vol. III (México: Porrúa, 1972), 115-29. For a discussion of the temporary constructions, *arquitecturas efímeras*, which were built in public spaces for holiday festivities and urban celebrations see Porfirio Sanz Camañes, *Las ciudades en la América hispana: siglos XV al XVIII* (Madrid: Sílex, 2004), 352-63.

⁵ Balbuena, *Grandeza*, 237. I am adapting López’s coinage “aquatic metropolis” from his work on viceregal period architecture in Mexico City. See John López, “The Hydrographic City: Mapping Mexico City’s Urban Form in Relation to its Aquatic Condition, 1521-1700” (PhD Thesis, MIT, 2013), 27.

the aesthetics of a Baroque city replaced Tenochca architecture.⁶ The city roads were no longer the place for canoes, and fields moved further outside the confines of the city.⁷

What Cortés and his companions saw in 1519, the Mexica—a Nahuatl-speaking Tepanec people—had built out of a small swampy island since 1325 and transformed into the strongest member of the Triple Alliance in 1428.⁸ Tenochtitlan held the strongest military of the three cities of the alliance, which included Texcoco and Tlacopan. When Cortés arrived it was not only the most powerful of the three but also the most beautiful. Tenochtitlan's striking layout, however, required a constant attention to matters hydraulic. The city's governors managed seasonal floods by way of a system of canals, causeways, and aqueducts, which required daily maintenance to prevent blockages and collapse. But from 22 May 1520 to 13 August 1521 the Spanish and their numerous indigenous allies, among them the Tlaxcalans, destroyed critical dikes and canals in a series of battles which also brought European smallpox to the city. By September 1521, Cortés gained control of the capital of the Aztec

⁶ Kubler observes that the design of large plazas built in early colonial New Spain exhibited the ideals of Renaissance writers and were an architectural leap ahead of many European cities: "The Mexican plazas... are unprecedented in general European practice, but for a very few exceptions. Their form is suggested, not in coeval European towns, but in Italian theory of the fifteenth and sixteenth centuries, where the relation between open spaces and house blocks was an object of constant study in the ideal urban layouts, by such men as Leone Battista Alberti, Antonio Averlino Filarete, or the author of the urban reveries of the *Hypnerotomachia Poliphili*." George Kubler, "Mexican urbanism in the sixteenth century," *Art Bulletin* (1942): 169.

Significantly, the first viceroy of New Spain's personal copy of Alberti's work on architecture is annotated in the viceroy's hand; it likely influenced Mexico City's urban layout. See Guillermo Tovar de Teresa, *La Utopía mexicana del siglo XVI: lo bello, lo verdadero y lo bueno* (México: Grupo Azabache, 1992), 19. Cuesta-Hernández's research on the book collections, thought, and writings of major sixteenth and seventeenth century architects in Mexico City is valuable. See: Luis Javier Cuesta-Hernández, "La teoría de la arquitectura en la Nueva España," *Destiempos* 14, no. Marzo-Abril (2008): 442-59.

⁷ Canoes were brought out during the floods of 1553 and 1607 during the term of Viceroy Luis de Velasco and then again during his son's second term. See F. de Cepeda and F.A. Carrillo, *Relación universal, 1637*, ed. F.G. de Cosío, Obras Públicas en México: Documentos para su Historia (México: Secretaría de Obras Públicas, 1976), 42, 58-61. Francesco Carletti's account for Ferdinando I de' Medici, Duke of Tuscany, mentions Mexico City's canal traffic in 1596: "There are many canals of water which flow by diverse routes and enter the lake on which the city is based. And on them the people come and go conducting their daily lives and everything else of which they have need with much comfort." Carletti, *Voyage*, 58.

⁸ For the political origins and structure of the *Tenochca* empire, see Pedro Carrasco Pizana, *The Tenochca Empire of Ancient Mexico: the Triple Alliance of Tenochtitlan, Tetzaco, and Tlacopan* (Norman: University of Oklahoma Press, 2011), 29; María Castañeda de la Paz, *Conflictos y alianzas en tiempos de cambio: Azcapotzalco, Tlacopan, Tenochtitlan y Tlatelolco (siglos XII-XVI)* (México: UNAM, 2013), 86ff.

Empire and made it the capital of a new viceroyalty: Nueva España.⁹ Under this designation—and *sans* former aesthetics and flood accommodating practices—Mexico City began to experience problematic seasonal floods.

The conquerors immediately set to replace the Temple complex at its centre with a viceregal palace, cathedral, and the main plaza and reinstated the canals and hydrology lost in battle.¹⁰ But the erratic flooding caused a vicious cycle of crop failures, famines, and a discontented populace within the city.¹¹ Because of damage to homes, shops, and buildings under construction like the cathedral,¹² commercial interests and overland transport were hampered in significant ways during the floods as roads between the city and the rest of the valley were cut off. By 1553 the

⁹ By 1531 the Crown had purchased from Cortés his centrally located dwelling on the main plaza for use as the viceregal palace. See George Kubler, *Mexican Architecture of the Sixteenth Century* (Westport: Greenwood Press, 1972), Vol. 1, 141-44.

¹⁰ Within the city, the Spanish continued to use Pre-Columbian water management techniques such as clearing the city's canals and *acequías* (open drains). As the Spanish concept of how cities functioned did not match the particularities of Tenochtitlan-Mexico City, even continuing many of the same water management practices did not prevent the flooding. Floods were perhaps less of a problem for Tenochca city architecture, as flooding may have been architecturally, or ritually, accommodated. Pre-Columbian temples and their surrounding civic buildings framed large central squares and were planned as backdrops for public, outdoor religious spectacles which included ball games. This "outdoor orientation" of Mesoamerican architecture can be contrasted with the European focus on building for interior space and comfort, and may explain one way that Tenochca civic architecture was less vulnerable than later Spanish edifices in times of flood. The arrival of iron tool technology with Spanish settlers dramatically changed construction practices as well as the shapes and uses of the buildings themselves. See Logan Wagner, Hal Box, and Susan Morehead, *Ancient origins of the Mexican plaza: from primordial sea to public space* (Austin: University of Texas Press, 2013), 42ff. For a study of Pre-Columbian building materials see Horacio Ramírez de Alba, Ramiro Pérez Campos, and Heriberto Díaz Coutiño, "El cemento y el concreto de los mayas," *Ciencia Ergo Sum* 6, no. 3 (1999): 275-84.

The degree to which flooding was problematic in Tenochtitlan likely changed over time; Hoberman references archeologists who have concluded that Tenochtitlan's hydraulic management was not wholly sustainable in the face of population growth and urban expansion. See: Louisa Hoberman, "Technological Change: The Case of the Desagüe in Colonial Mexico," *Technology and Culture* 21, no. 3 (1980): 406n.59.

¹¹ Viceroy Luis de Velasco senior's untitled letter to Madrid of 1555 notes both a wheat and corn crop failure resulting from a prior flood. (The letter was found by the viceroy's twenty-year old grandson, Juan de Altamirano y Velasco, Conde de Santiago y Calimaya (1616-1661), in an old book of the viceroy's letters, duplicates of those sent to Spain; see Cepeda and Carrillo, *Relación*, 45. The Condes de Santiago family palace is now the Museo de la Ciudad de México.) An exhaustive tabulation of agricultural shortages in the Valley of Mexico from 1525 to 1809 can be found in Charles Gibson, *The Aztecs under Spanish rule: a history of the Indians of the Valley of Mexico, 1519-1810* (Palo Alto: Stanford University Press, 1964), Appendix V.

¹² The ongoing construction of the Cathedral was a point of special concern and pride for many city officials; the Royal Audiencia of New Spain informed Charles V on 16 September 1555 that the Cathedral construction had been interrupted by heavy rains and flooding. See, Cepeda and Carrillo, *Relación*, 45-46. Viceroy Juan de Mendoza y Luna (October 1603-July 1607) toured the Cathedral scaffoldings daily and gave the builders coins as encouragement. See *ibid.* As a work of aesthetic and religious import as well as a structural focal point of the *plaza mayor*, the city's principal church building displayed a significant investment of resources and, like its counterparts in Europe, took decades to complete. Visiting and local officials alike expected a degree of grandeur when attending Mass at a capital city cathedral, and competitions with architects working on comparable structures in nearby cities—such as Puebla—were not uncommon.

mismatch between the city's original layout—an island with inroads for lake waters to flow through and a combination of canoes, roads, and causeways for transport—and the Spanish concept of what a capital city, with roads for horses and carts, should look like, became clear.¹³ The colonial era *desagüe* (water management) was an endeavour to address the consequences of transplanting a European model of the city to the Valley of Mexico by diverting the flood waters of Mexico City's surrounding lakes.

Current scholarship on hydraulic engineering in colonial New Spain has generally viewed the transformation of Tenochtitlan into Mexico City as a Sisyphean battle against topography or the mythic loss of a second Atlantis. Among others, Hoberman, Osorio-Barrera, López, and Candiani have examined in comprehensive studies the project's significance for early modern science.¹⁴ But they have not discussed the role that debate and the writings of hydraulic engineers played in the *desagüe* project. Vera Candiani's *Dreaming of Dry Land* is an excellent study of the *desagüe* project's structural artifacts and their impact on the ecology of Mexico City's water systems over the long term. The emphasis of my narrative is different. This is a new reading of the ways in which debate and discourse affected the selection of Desagüe project leadership during its first forty years. The Desagüe project developed from the perspectives of well-travelled engineers who carried with them—and also produced their own—unique sets of scientific books. Head engineers of the project bore their *sui generis* training in mathematical calculation, geometric representation, and hydraulics along with knowledge gained from experience in diverse topographies. It is not surprising that creative problem solvers would disagree about the optimal solutions to a complex challenge.

This chapter examines how the municipal council records and book publications shaped the community of *desagüe* engineers of Mexico City, 1600-1650. Eyewitness accounts of the viceregal capital during the seventeenth century portray its uniquely hybrid culture. Primary among these sources is the *Relación Universal de 1637* (Mexico City, 1637), a collection of government decrees, proceedings, and

¹³ The Mexica recorded three major floods in Tenochtitlan. Ibid., 41.

¹⁴ See Louisa Hoberman, *City Planning in Spanish Colonial Government: the Response of Mexico City to the Problem of Floods, 1607-1637* (New York: Columbia University, 1972); Antonio Barrera-Osorio, "Experts, Nature, and the Making of Atlantic Empiricism," *Osiris* 25, no. 1 (2010); López, "Hydrographic City."; Vera Candiani, *Dreaming of Dry Land: Environmental Transformation in Colonial Mexico City* (Palo Alto: Stanford University Press, 2014). An accessible guide to the primary sources is Michael Mathes, "To save a city: The Desagüe of Mexico-Huehuetoca, 1607," *The Americas* (1970): 419-38.

debates which took place between 1570 and 1636.¹⁵ The *Relación* documents city hydraulic management enacted by those administrators who sought long-term solutions to the environmental duress of rainy season floods, which usually occurred during the summer months (May through October). The third Marquis of Cerralvo, viceroy Rodrigo Pacheco y Osorio de Toledo's history is a principal source to analyze the *desagüe* project—a rich source that has not been thoroughly used by other historians.¹⁶

A Cosmopolitan Capital City and Engineers in New Spain

The fitful early period of the *desagüe* featured a host of figures whose interests were tied to the fluctuations in lake waters and the success of the water management project. Before discussing viceroys, clerics, engineers, and merchants who each had a stake in the endeavour, however, it is useful to briefly outline the city's demographics, starting at the *plaza mayor* and expanding outwards. From 1524, viceroys and ministers, who included indigenous elites, or *principales*, worked at the viceregal palace. European and Spanish residents inhabited the city centre. Black domestic servants shared the city centre and congregated at the markets between errands and during their off hours.¹⁷ Then there resided first- and second-generation *criollos*, encircled by neighborhoods of local mestizo, free mulatto, and East Asian inhabitants, all outnumbered by the indigenous population.¹⁸ Many homes were slightly lower in

¹⁵ Cepeda and Carrillo, *Relación*. Other mid seventeenth-century printed books concerning the floods not consulted: Francisco de Lorra Baquío, *Lamentación sobre la terrible inundación que padeció México* (México, 1629); Juan de Cervantes Casaus, *Informe sobre el estado de las Lagunas de México y reparos que pueden intentarse* (México, 1629); Juan de Villabona, *Juicio sobre el desagüe de las Lagunas de México* (México, 1636); Arias Alonso, *Impugnación del proyecto de desagüe y obra de Enrico Martín* (México, 1637); N. Espinosa, *Parecer sobre la obra del desagüe de las Lagunas de México* (México, 1637); Andrés Fernández Hipensa, *Informe..para los materiales del desagüe* (México, 1637).

¹⁶ Five hundred copies of the work were published in its first edition. Ibid., 13.

¹⁷ For case studies from Inquisition documents on the private lives of Africans and Creoles during the first half of the seventeenth century see Herman Bennett, *Colonial Blackness: a History of Afro-Mexico* (Bloomington: Indiana University Press, 2011), 54.

¹⁸ The broad demographics of New Spain were roughly 1:1 Africans to Spanish/Europeans, and 12:1 Indigenous to the rest of the population in 1646. Ibid., table 2.1. The figures for the Archdiocese of Mexico City show a greater number of European residents: 102,544 ethnic Europeans (including those locally born); 643,190 Indigenous (including the children of intermarriage who participated in indigenous communities); 62,814 ethnic Africans (including those locally born). The figures were extracted from Church records by Gonzalo Aguirre Beltrán, *La población negra de México: estudio etnohistórico* (México: FCE, 1972), 219. Humboldt's population estimates for Mexico City in 1803 show a larger Spanish sector of the capital: 49% Spanish, 24% Indigenous, 6% Mulato, 2% European, and 19% Other. Miguel Wionczek, ed. *Alejandro de Humboldt: tablas geográficas políticas del Reino de Nueva España y correspondencia Mexicana* (México: Dir. de Estadística, 1970), 50.

elevation than the plazas and roads, which resulted in water runoff entering them during floods,¹⁹ and by the early seventeenth century this continued vulnerability to deluges fuelled popular uprisings, such as those in 1612 and 1624.

The concerns of the indigenous majority recur as a deciding factor in the desagüe-related actions of the viceregal administration during the terms of Luís de Velasco (r. November 1550-July 1564) and his son, Luís de Velasco the Marquis of Salinas (r. January 1590-November 1595 and July 1607-June 1611).²⁰ During their terms as viceroys, the Velascos displayed a notable commitment to the Crown's mandates to protect indigenous subjects. Velasco Senior's letter (6 June 1556) to the Corregidor de Antengo, García de Valverde, shows the viceroy being exceptionally careful not to upset the indigenous population. Velasco requests that Valverde establish a spillway into the marshland near the Tula River and be conscientious about minimising any disturbance to the surrounding indigenous communities; the viceroy diplomatically asked García de Valverde to pay attention to the current attitudes of the indigenous governors (and workers) towards the spillway and to complete the work quickly so as to avoid inconveniencing them. Velasco Senior as well as his predecessor, Antonio de Mendoza, were favourably portrayed by indigenous chronicles as attentive, if paternalistic, visitors to the villages.²¹ Despite exposure to

For this period, the label "Chino" includes the Goan, Malaccan, Japanese, Filipino, and Chinese inhabitants of New Spain. Many members of the South and East Asian populations who arrived in New Spain as slaves achieved manumission by legally becoming "Indios." See Tatiana Seijas, *Asian Slaves in Colonial Mexico: from Chinos to Indians* (Cambridge: Cambridge University Press, 2014), 117. Chinese merchants and settlers in New Spain have been studied for their role as medical practitioners, see Slack, "Chinos," 35-67. Archival sources produced by seventeenth-century Japanese residents in New Spain have recently become better known, see Melba Falck Reyes and Héctor Palacios, *El japonés que conquistó Guadalajara: la historia de Juan de Páez en la Guadalajara del siglo XVII* (Guadalajara: Universidad de Guadalajara, 2009), 25ff. Ecclesiastical records are not the only sources available for investigating ethnic and religious diversity in Mexico City as demonstrated by: Nicole von Germeten, *Black Blood Brothers: Confraternities and Social Mobility for Afro-Mexicans* (Gainesville: University Press of Florida, 2006), 19; Ryan Dominic Crewe, "Brave New Spain: An Irishman's Independence Plot in Seventeenth-Century Mexico," *Past & Present* 207, no. 1 (2010): 53-87.

¹⁹ Cepeda and Carrillo, *Relación*, 45.

²⁰ Between his two terms as viceroy of New Spain, Velasco Junior governed Peru as viceroy (July 1596 - January 1604).

²¹ Cepeda and Carrillo, *Relación*, 44. See Stephanie Wood, *Transcending conquest: Nahua views of Spanish colonial Mexico* (Norman: University of Oklahoma Press, 2003), 41-42; Jorge Ignacio Rubio Mañé, *D. Luis de Velasco, el virrey popular* (México: Ediciones Xochitl, 1946), 49-50. Chimalpahin also recorded events in the lives of Velasco Junior, his wife, son, and daughter in a positive light, see Domingo Francisco de San Antón Muñón Chimalpahin Cuauhtlehuanitzin, *Annals of his time: Don Domingo de San Antón Muñón Chimalpahin Quauhtlehuanitzin*, eds. James Lockhart, et al. (Palo Alto: Stanford University Press, 2006), 35, 139ff. Velasco Senior's orders from Charles V included a detailed plan for preventing the enslavement of the indigenous peasants and protecting them from predatory taxation. If the recommendations reflect viceregal actions then, the viceroy visited indigenous villages and mines in order to observe, inquire, and listen to the villagers on the matter of

plagues and European illnesses such as smallpox and typhus,²² the native population remained politically influential, particularly the upper strata of indigenous elites, who continued to exercise power within the viceregal government.²³

This was the Mexico City of indigenous intellectuals such as Fernando de Alva Ixtlilxochitl (1578-1648), Chimalpahin (1579-1660), Bartolomé de Alva (b. circa 1597), and Juan Buenaventura Zapata y Mendoza (b. circa 1600-1688), each of whom chronicled a culturally rich indigenous society.²⁴ Indigenous elites often dressed in the Spanish manner, particularly those who, like the children of Moctezuma, had returned from travels in Spain.²⁵ Beyond Mexico City, they made adept use of the Spanish legal system to successfully petition the king in Madrid for

how much and to whom they paid tributes as well as any other concerns they had. Enslaved indigenous workers were freed and paid for their labour; forced workers were allowed to relocate to an indigenous village where they would farm or practice a trade and move between towns as they wished. See, Antonio de Mendoza, "Lo que el Visorey e Gobernador de la Nueva España y sus Provincias... ha de hacer en dicha tierra...por mandado de S. M.," in *Colección de Documentos Inéditos del Archivo de Indias* (Madrid: AGI, 1875), 520-47. Also see "Relación, Apuntamientos y Avisos, que por mandado de S. M. dió D. Antonio de Mendoza, Virrey de Nueva España, a D. Luis de Velasco, nombrado para sucederle en este cargo," in *Colección de Documentos Inéditos del Archivo de Indias* (Madrid: AGI, 1866), 484-515. For a discussion of "the historically remarkable feature of Spanish colonization" according to Gibson, that was a "concern for the welfare of native peoples," see Charles Gibson, *Tlaxcala in the Sixteenth Century* (New Haven: Yale University Press, 1952), 190-93.

²² Census figures collected by administrators during Viceroy Martín Enriquez de Almanza's term (1568-1580), suggest that 40-50% of the indigenous population in the Valley of Mexico suffered from the *cocoliztli* plague of 1576-1579; see, Barrera-Osorio, "Experts," 141. (Also see Gibson's Appendix IV, for all known epidemics from 1520 to 1810.) By Semo's reckoning the total indigenous population of New Spain in 1646 was at 74.6% of its starting figure: Enrique Semo, *The History of Capitalism in Mexico: its Origins, 1521-1763* (Austin: University of Texas Press, 1993), 155, Table 6.

²³ Indigenous colonial governors were appointed from elite families that had held power before the arrival of Cortés. For a discussion of the intra-familial struggles for power that this sparked, see María Castañeda de la Paz, "Historia de una casa real: Origen y ocaso del linaje gobernante en México-Tenochtitlan," *Nuevo Mundo Mundos Nuevos* (2011): <http://nuevomundo.revues.org/60624>. Recent ethnohistorians have recounted the military, and associated political, significance of Mesoamerican warriors within the government of New Spain, see Laura Matthew and Michel Oudijk, *Indian Conquistadors: Indigenous Allies in the Conquest of Mesoamerica* (Norman: University of Oklahoma Press, 2007), 28ff; Matthew Restall, *Maya Conquistador* (Boston: Beacon Press, 1998), 104ff.

²⁴ Their accounts of the arrival of the Spanish portray distinct indigenous *calpulli* making use of the Spanish to overthrow tyrannical Tenochca overlords. See Fernando Alva Ixtlilxóchitl, *The Native Conquistador: Alva Ixtlilxochitl's Account of the Conquest of New Spain*, eds. Amber Brian, et al. (University Park: Penn State University Press, 2015), 4ff. Chimalpahin's corrected edition of Francisco López de Gómara's *General History of the Indies* (1552) introduces indigenous participants into the account of Spanish conquest; see Domingo Francisco de San Antón Muñón Chimalpahin Cuauhtlehuanitzin, *Chimalpahin's Conquest: A Nahua Historian's Rewriting of Francisco López de Gómara's La conquista de Mexico*, trans. Susan Schroeder (Palo Alto: Stanford University Press, 2010), 17ff. Conquistador Bernal Díaz was also inspired by Gómara's errors to write his own *Historia Verdadera* which circulated from 1575 and was published posthumously in 1632. Significantly Gómara's work was banned by Philip II for being excessively pro-Spanish in its account of the conquest. The example illustrates that banned books circulated in Mexico City, and that revisionist narratives of the conquest formed part of the intellectual discourse of the time. For examples of grassroots indigenous political activism outside the cities consult Gruzinski, *Man-gods*, 31-104.

²⁵ Castañeda de la Paz, "Historia de una casa real." Some non-elites, *maceguales*, also dressed in European-style clothing as indicated by sumptuary licences cited by Wood, *Transcending*, 59.

rights to primordial lands, tribute, and royally approved emblems of status.²⁶ And during the seventeenth century, public theatre and reenactments of semi-historical events also took place during annual festivals and displayed complex indigenous perspectives on the Spanish conquest.²⁷

The lives of these indigenous elites coincided with those of the astronomer Diego Rodríguez (1569-1668) and one of his well-known *tertulia* members, the architect/book collector, Melchor Pérez de Soto (1606-1656). A culture of Spanish Golden Age learning bloomed during the second half of the seventeenth century, the heyday of glamorous baroque intellectuals like the proto-feminist poet, Sor Juana Inés de la Cruz (1651-1695) and the cosmographer/historian Carlos Sigüenza y Góngora (1645-1700).²⁸ Many of these figures were “colleagues” who invested in the preservation of Mexico City’s documents and libraries, and used the same public routes to the viceregal palace, cathedral, printing houses, bookshops, eyeglass vendors, and university, all within or adjacent to the Plaza Mayor.²⁹ These intellectual

²⁶ Castañeda de la Paz, María Castañeda de la Paz, “Central Mexican Indigenous Coats of Arms and the Conquest of Mesoamerica,” *Ethnohistory* 56, no. 1 (2009): 125ff. Stephanie Wood and Robert Haskett have argued that indigenous negotiations with the Spanish colonial enterprise show that they did not necessarily self-identify as subject peoples: “While it is true that all over early New Spain the indigenous population displayed a general willingness to embrace Christianity...they did not believe that this...required them to assume the status of a subjugated people.” Robert Haskett, “Conquering the Spiritual Conquest in Cuernavaca,” in *The Conquest All Over Again: Nahuas and Zapotecs Thinking, Writing, and Painting Spanish Colonialism*, ed. Susan Schroeder (Portland: Sussex Academic Press, 2010), 245. See also Wood, *Transcending*, 148-49.

²⁷ Public theatre was an especially visible arena where indigenous actors appropriated Spanish cultural narratives and inverted the roles of conqueror and conquered. A striking example of this kind of reinterpretation was the Tlaxcala Corpus Christi festival of 1539; see Barry Sell and Louise Burkhart, eds., *Nahuatl Theater*, vol. 4 (Norman: University of Oklahoma Press, 2008), 51ff; Toribio Motolinía, *Motolinía's History of the Indians of New Spain* (Washington, D.C: Academy of Franciscan History, 1951), 109-10. World traveller Gemelli Carreri noted during his visit to Mexico City in 1697 that indigenous actors performed in the large theatrical productions which he attended. See, Giovanni Gemelli Carreri, *Viaje a la Nueva España*, ed. José de Agreda (México: UNAM, 2002), Libro I, 75.

²⁸ Boyer calls seventeenth-century Mexico City “stylish and ostentatious”; Boyer, “Mexico,” 478. Sor Juana is but one of a group of intellectual women who wrote about their interests in science and facility with mathematics. See Josefina Muriel, *Cultura femenina novohispana* (México: UNAM, 1982), 472ff; “Lo que leían las mujeres de la Nueva España,” in *La literatura novohispana: revisión crítica y propuestas metodológicas* eds. José Pascual Buxó, et al. (México: UNAM, 1994), 159ff. For women who administered printing houses see: Marina Garone Gravier, “Impresoras hispanoamericanas: un estado de la cuestión,” *Boletín de la Real Academia de Buenas Letras de Barcelona* 51 (2008): 452; Nancy Joe Dyer, “Sermons of Colonial New Spain and their Women Printers, a Family Business,” in *El sermón novohispano como texto de cultura*, ed. Blanca López de Mariscal (New York: Instituto de Estudios Auriseculares, 2012), 49ff. See also Ken Ward’s studies on the printers María Candelaria de Ribera and Paula de Benavides: Kenneth Ward, “Mexico, where they coin money and print books: the Calderón Dynasty and the Mexican Book Trade, 1630-1730” (Ph.D. Thesis, University of Texas at Austin, 2013), 58,85.

²⁹ The local circulation and reception of texts produced by this milieu was strongly influenced by access to the viceregal court. Sor Juana and Sigüenza y Góngora are paradigmatic of the *criollo* intellectuals who mingled with the viceroys’ guests and dignitaries; abroad Sor Juana’s poetry was published in Spain during her lifetime while Sigüenza y Góngora corresponded with astronomers on

figures, as had earlier Mexica elites, likely escaped the floods during the rainy season for nearby cities like Puebla de los Angeles—or other urban centres in the Valley of Mexico where the rains were less troublesome—and then returned wearing leather boots to navigate the muddy roads.³⁰

In Mexico City, Indigenous and European scholars were central figures in the intellectual milieu of formal and informal debate during the significant first decades of the desagüe project, c.1620s-1650.³¹ But closer to the action of hydraulics in the city were the highly mobile mining engineers—often trained in Europe but also including local or indigenous talents—who tended to spend time in the viceregal capital before moving outwards to the coasts or mountains.³² Mine owners used pumps and, near sources of running water, sluicing mechanisms to drain their flooded shafts.³³ Refinery towns where ore was processed were largely dependent upon oxen

the Iberian Peninsula. As for the local influence of published and manuscript works, it is clear that Chimalpahin translated into Nahuatl parts of—royal cosmographer and desagüe project manager—Enrico Martínez's *Repertorio de tiempo e historia natural de Nueva España* (Mexico City, 1606) for the annals. Whether Martínez read Chimalpahin's work in return is unknown, but a generation later, another royal cosmographer, Sigüenza y Góngora, counted Chimalpahin's writings among his books. See: Susan Schroeder, "The Annals of Chimalpahin," in *Sources and Methods for the Study of Postconquest Mesoamerican Ethnohistory, Provisional Version*, eds. James Lockhart, et al. (Eugene: Wired Humanities Project, University of Oregon, 2007), <http://whp.uoregon.edu/Lockhart/index.html>.

For evidence of eyeglass and optical lens use in Mexico City during this period see María Luisa Calvo and Jay Enoch, "Acerca del uso de lentes correctoras en las colonias españolas del nuevo mundo: una referencia al Virrey Luis de Velasco y la tecnología de su época (s. XVI)," *Óptica Pura y Aplicada* 35 (2002): 1-6.

³⁰ During the precolonial period, Mexica rulers retired to the wooded hills and sacred springs of Chapultepec. Cortés' second letter to Charles V in 1520 describes the Nahua aristocracy of Tenochtitlan as having fine "houses in the city, in which they reside a certain part of the year." Though he does not state explicitly why they spend only part of the year in the capital, the surrounding description of the city's hydrology suggests that those with resources left the city during its rainy season in the same way that Sigüenza y Góngora and Sor Juana are known to have visited Puebla, separately, when they could.

Gemelli Carreri notes in his travelogue of 1698 that he needed to wear boots during his visit to Mexico City because the streets were muddy; see Gemelli Carreri, *Viaje*, 146. Regarding leather boot production in New Spain, Carletti mentions the exportation of hides from New Spain to Spain. Carletti, *Voyage*, 66. The success of cattle ranching in New Spain meant that leather footwear may have been produced locally but was more likely imported. See Bishko, "Peninsular Background," 491ff; Dusenberry, *The Mexican Mesta: the Administration of Ranching in Colonial Mexico*, 40.

³¹ Between 1533 and 1577 the Colegio de Santa Cruz de Tlatelolco educated the sons of Mexica elite. Those who already knew how to read and write in Castilian were admitted, and they were taught the seven liberal arts while being groomed for political office. The *Badianus Codex*, a botanical work that predated Francisco Hernández's expedition, was written and translated into Latin by two Xochimilca students of the Colegio in 1552.

³² Jorge Ignacio Rubio Mañé, *El virreinato: expansión y defensa* (México: UNAM, 1983), 153.

³³ Peter Bakewell, "La periodización de la producción minera en el norte de la Nueva España durante la época colonial," *Estudios de Historia Novohispana* 10, no. 10 (1991): 31-43. Recently scholars have used early colonial records from the Hospital de San Juan de Dios in Zacatecas to clarify the medical institutions and practices that developed alongside principal mines and refining plants and found that some mine owners invested in maintaining the health of their employees by paying to have

or mule-power, though they sometimes required a river to run sluices and a grinding mill which required the occasional attention of engineers.³⁴

Mexican mining expertise became known globally, extending to both the Atlantic and Pacific worlds. In 1609 Shogun Iyeyasu Tokugawa requested “that as many as fifty expert miners be sent to Japan from Mexico...to teach the Japanese the most advantageous methods of working their gold mines...[on] the Island of Sado.” The request went unacknowledged because of a diplomatic miscalculation, but the fact that it was made suggests the existence of a community of engineers, sought after in the Pacific, that could be accessed via Mexico City.³⁵ Mining engineers were not the only mechanically minded specialists to be found an ocean away from the metropolises of Europe and Asia.³⁶ The city attracted European engineers of different kinds with diverse specializations, among them engineers from newly Protestant lands in Dutch and German-speaking regions.

The problem of the city and its seasonal flooding drew upon an abundance of engineering skills in New Spain. Immigration records show two related flows of trained human capital: engineers who migrated from different parts of Spain to New Spain and engineers from Protestant regions who responded to the Spanish Crown’s contract openings. How many of the former are included within the latter is not currently known. Since there were German miners in the 1530s in the Caribbean and in Peru it is plausible that some were also in New Spain as early as the beginning of the viceregal period in 1535.³⁷

The engineering community of Mexico City during the first third of the seventeenth-century certainly included a diverse and international skillset. An Andalusian architect (Fray Andrés), a multi-talented German printer (Enrico

physicians on-site or establishing local hospitals. Labourers were ethnically diverse (European, Indigenous, African, Creole, Mestizo), and the vast majority of mine labourers were free persons motivated by high wages. (See Alexander von Humboldt, *Political essay on the Kingdom of New Spain*, trans. Mary Maples Dunn (New York: Knopf, 1972), 163.) It was dangerous, physically taxing work and just as unhealthy as mining in Hungary and the German-speaking lands during the sixteenth century based on the descriptions in Georgius Agricola’s *De Re Metallica*. See José Raigoza Quiñónez, *La historia del Hospital de San Juan de Dios en Zacatecas* (Zacatecas: Universidad Autónoma de Zacatecas, 2007), 83, 120.

³⁴ Barrera-Osorio, *Experiencing Nature*, 65-71.

³⁵ Nuttall, *Earliest Historical Relations*, 10. Diplomatic relations between New Spain and Japan strengthened following the Shogun’s missive and marked a high point before the closing of Japan’s ‘Christian Century’ in the mid-1630s.

³⁶ Julio Sánchez Gómez, *De minería, metalúrgica y comercio de metales: La minería no férrea en el Reino de Castilla (1450-1610)* (Salamanca: Universidad de Salamanca, 1989), 491, 526-37.

³⁷ Calderón Quijano, “Ingenieros militares,” 21-27; Barrera-Osorio, *Experiencing Nature*, 67.

Martínez, born Heinrich Martin), and a Dutch engineer (Adrian Boot), whose drawings of Veracruz remain our best visual source for the time, were among those whose skills were important to the largest hydraulic project of the day. As civil, hydraulic, military, and mining engineers, these experts sought solutions to construction problems using specialized instruments and tools which traveled with them, mechanized pumps and pulleys which they likely built on location, sometimes to the specifications recorded elsewhere, and reference works both printed and manuscript.³⁸ Their tools, however, were less interesting than the constraints and opportunities provided by their new environment in Mexico City. The city offered some of the social features which bolstered the scientific revolutions in Europe—collaborative trialling of engineering proposals, debate and discussion, and a diversity of experience from abroad. The local discussions about the desagüe project were competitive and lively, as we shall see.

Transforming the Nature of the City: The Amphibious City, 1550-1604

According to visual representations of the city produced between 1522 and 1725, the capital underwent visible transformations in size, building style, and most significantly infrastructure. A glance at some depictions of Mexico City printed in Europe between 1522 and 1725 gives an idea of these changes. The map called ‘La gran ciudad de Temixtitan, 1521,’ known as the Cortés map, shows the Mexica city surrounded by water and crisscrossed by canals (figure 3.1). This depiction also includes details—such as multiple skull racks in the main square—that strongly suggest the map included native input or was adapted from a native visual source. The ‘Uppsala Santa Cruz Map’ produced by *tlacuiloque*, scribes, at the request of the first viceroy of New Spain circa 1540, is the first map of the now Spanish city (figure 3.2).³⁹ In the map we can see that there are still canals in the capital, and Mexico City

³⁸ Martens’ observation that “the circulation of engineers was accompanied by a prodigious traffic of media such as books, prints, drawings and models” in northern Europe of the sixteenth through eighteenth centuries also applies to the far western end of the Spanish empire; see, Pieter Martens, “Engineers and the Circulation of Knowledge in the Spanish Netherlands,” in *Embattled Territory: The Circulation of Knowledge in the Spanish Netherlands*, eds. Sven Dupré, et al. (Ghent: Academia Press, 2015), 91.

³⁹ The map was produced at the same Colegio de Santa Cruz de Tlatelolco, inaugurated by bishop Juan de Zumárraga and Viceroy Antonio de Mendoza, that trained the children of elite Mexica and produced well-known works such as Sahagún’s Florentine Codex. Franciscans began teaching at that site from 1533 and likely chose the location because it had previously been a *calmecac*, where adolescent Mexica nobles received their religious and military training. For a discussion of Nahua educational practices and values see León-Portilla, *Aztec Thought*, 135-50.

appears disproportionately large in relation to the lakes. The ‘Plan of Mexico City 1628’ by Juan Gómez de Trasmonte, architect of the Cathedral of Puebla, was produced for the desagüe project. It shows a baroque city surrounded by water on three sides, with long straight streets (figure 3.3). During the mid-seventeenth century the capital covered an area of roughly 4 km north-south by 2.5 km east-west, and its buildings were still prone to water damage.⁴⁰

Of the ten extant images depicting the city in this period (Table 3.1), four in particular provide useful eye-witness representations: the Cortés map of 1521; the ‘Uppsala Santa Cruz Map’; the map by Trasmonte; and the detailed ‘Plano de la ciudad de México (1737)’ produced by Mexico City architect Pedro de Arrieta.⁴¹ These images show that the city grew—expanding to the north and west until it joined Tlacopan on dry land in a neighborhood now known as Tacuba. The later maps also suggest that the desagüe project had reduced water levels in the Laguna, though not yet significantly. The 1758 map produced in Paris under the official auspices of the Bourbon monarchy shows a small lake between the two causeways—Tlacopan and Chapultepec—that connected the city to dry land, rather than the channel that had existed before. Though it does not provide an eyewitness representation it does synthesize current firsthand data about the city and also suggests that European viewers within elite circles witnessed Mexico City from home. Humboldt’s geographic renderings during his visit to New Spain indicate that, by 1803, the central plaza of Mexico City was “one meter, one foot and one inch above the level of the lake waters”.⁴²

⁴⁰ Cepeda and Carrillo, *Relación*, 41. The measurements taken were 4,000 varas by 2,500 varas.

⁴¹ The Nahuatl term *tlacuilo* indicates scribes and artists who produced official records for the *tlatloani* (ruler). For a recent study of the Uppsala Map see: John López, "Indigenous Commentary on Sixteenth-Century Mexico City," *Ethnohistory* 61, no. 2 (2014). For a useful study of Pedro de Arrieta’s cadastral map, see de la Maza and Ortiz Macedo, *Plano de la Ciudad*, 59ff.

⁴² Humboldt, *Political Essay on the Kingdom of New Spain*, Book III, 82.

Figure 3.1: La Gran Ciudad de Temixtitan, c. 1521⁴³

Figure 3.2: Uppsala (Santa Cruz) Map, c. 1540

⁴³ The maps and portraits in this thesis are from <https://commons.wikimedia.org/>

Figure 3.3: Plan of Mexico City 1628 by Juan Gómez de Trasmonte

Table 3.1: Visual Representations of Mexico City, 1521-1755

Image	Year Represented
‘View of Tenochtitlan’ 1522 Woodcut from <i>Neue Zeitung von dem lande das die Spanier funden haben ym 1521 yare genant Jucaton</i> [John Carter Brown Library]	c.1521
‘La gran ciudad de Temixtitan [Tenochtitlan]’ Woodcut from <i>Praeclara Fernanandi de Nova Maris Oceani Hispania Narratio</i> (Nuremburg, 1524) [Newberry Library]	1521
‘Santa Cruz / Uppsala Map.’ 1540. Watercolour on Parchment. Nahua artists patronized by Viceroy Antonio de Mendoza. [Uppsala University Library, Sweden]	c.1540
‘A View of Mexico City from 1572’ Georg Braun and Franz Hogenberg. "México Regia Celebris Hispaniae Novae Civitas," from <i>Civitates Orbis Terrarum, Liber I</i> . Frankfurt: Braun and Hogenberg, [1572]. [South Carolina College Library, Special Collections]	c.1550
‘Plan of Mexico City 1628’ Juan Gómez de Trasmonte. Ink and wash on paper. [Biblioteca Laurenziana]	1628
‘Nova México’ 1671 engraving in John Ogilby’s <i>America</i> . [Biblioteca Nacional de España]	c.1650

'México' engraving from Carol Allard, <i>Orbis habitabilis oppida et vestitas</i> . Amsterdam, 1681 [Biblioteca Nacional de España]	c.1550
'La muy noble y leal ciudad de México' 1690-92. Anon. Biombo [Folding Screen]. Oil on Wood. [Museo Franz Mayer, Mexico City]	1690
'Plano de la ciudad de México' 1737. Pedro de Arrieta. Oil on Canvas. [Museo Nacional de Historia, Mexico City]	1737
'Plano de México' 1758. Engraving from Tomás López de Vargas, <i>Atlas geográfico de la América septentrional y meridional 1758</i> [Museo Naval, Madrid]	c. 1750

From the time of its uniquely aquatic founding, floods were endemic to Tenochtitlan. Three major floods are recorded for its prehispanic period from 1325 to 1519: the first occurred during its fifth ruler's reign, Moctezuma Ilhuicamina (1440-1464); the second during Ahuizotl's reign (1486-1502); and the third during the reign of Moctezuma Xocoyotzin (1502-1520).⁴⁴ Part of the Tenochtitlan-Mexico City's system for water management involved an elaborate framework of drains. In the year 1637, 1.66 km of drains crossed the city.⁴⁵ Seven drainage canals are known to have lined particular quarters of the city: the drain that passed in front of the palacio was 3 km long; the one in front of the Convento del Carmen 1.1 km long; in front of the Convent-Church of la Merced 2.1 km, the one known as "Capitel" was 2 km; Tezontla's 1.6 km; the Ermita de Santa Ana's 3.8 km; and the one coming from Mexicaltzingo, which passed in front of the Royal Mint, was 2.9 km.⁴⁶ All drains flowed to the Laguna (the lake waters surrounding the city) and had gates that were opened each morning to release the city's water. Each evening they were closed to prevent northerly currents from pouring into the city's drains during the night. The city's precipitation levels fluctuated widely, a drought one year and moderate or heavy rains another; generally, the city experienced a mild rainy season and flooding was not constant. The drains, however, were insufficient to prevent flooding during long stretches of heavy rain.

⁴⁴ The dike built by Nezahualcoyotl—*tlatoani* of the allied city Texcoco (1429-1472)—divided Lake Texcoco into two unequal parts with most of the waters on the Texcoco side, and became an important component in Mexico City's hydraulic system. During the viceregal period, it was referred to as the *Albarradón de San Lázaro*.

⁴⁵ The *Relación Universal* figures are given in *varas* which I have converted into kilometres. A vara is nearly one metre in length.

⁴⁶ Cepeda and Carrillo, *Relación*, 40-41.

Understanding water management in early colonial Mexico City requires envisioning the extent to which a Renaissance city model of road traffic was placed on an island of reclaimed land within a system of six lakes. According to local lore, the city's ground floor was built up from structures placed on top of *chinampas* (artificial islands) arranged to create roads of different types: canals traversed by canoes, mixed-use canals with sections of earthen walkways, and pedestrian walkways alone. The Spanish repurposed an urban landscape which was originally developed for transportation via canoes and canals.⁴⁷ This transformation of an amphibious city into a more familiar one of roads, horses, carts, and mules took ten generations and was only deemed complete at the end of the eighteenth century.⁴⁸ Refashioning the city had the effect of gradually transforming the river topography of indigenous villages surrounding it.⁴⁹

Cortés's impetuous decision to found his capital, atop what the Nahua had converted into a garden fortress surrounded by lakewaters and accessed via canals, made symbolic sense.⁵⁰ Just as the Romans had done before them, the Spanish conquest required replacing previous images of divine and political power with those of the conquerors.⁵¹ However, persisting with the site of the capital when "there were better sites two leagues or so away" (such as Azcapotzalco, Tlacopan, Chapultepec, Texcoco), rather than an ongoing display of rash potency, may have been a result of a

⁴⁷ The fact that Mexico City had canals seems to have circulated in Europe beyond the distribution of the map that Cortés included in his letters to Charles V. The canals resonated with viewers who imagined a city such as Venice from the looks of an early sixteenth-century woodcut, 'View of Tenochtitlan' from *Neue Zeitung von dem lande das die Spanier funden haben ym 1521 yare genant Jucaton* (Erfurt: Matthes Maler, 1522).

⁴⁸ By the late sixteenth century carriages were also present in the city. Chimalpahin Cuauhtlehuanitzin, *Annals*, 45, 169. The carriages were pulled by horses which did well in the city: Carletti admired the jennet horses of Mexico City which he said thrived on a tender rush or grass that grew in the lake. Carletti, *Voyage*, 59. The grass appeared, or was introduced, after the first viceroy's term, as Antonio de Mendoza listed the lack of horse fodder among the top-priority concerns for his successor Velasco Senior to improve. Though a seemingly minor point, the introduction of horses, and turf, in Mexico City illustrates the rapid impact that European horse culture had upon the natural environment. See: Rubio Mañé, *Virrey popular*, 53.

⁴⁹ See Candiani, *Dreaming of Dry Land*, 121ff.

⁵⁰ The dike built by Aztec ruler Nezahualcoyotl in 1449 separated the brackish waters of Lake Texcoco and Lake Zumpango from the fresh waters of Lakes Xochimilco and Chalco. These fresh waters came from an artesian spring and supported the fish and *chinampa* agriculture for the city. The salt index of Lake Texcoco, on the other hand, sterilized the former fields along its banks. The eighth Aztec ruler, Ahuizótl, made Tenochtitlan into a place of gardens and orchards from 1486.

⁵¹ For work on New World uses of Greco-Roman models and texts during the early colonial period consult the later publications of Classicists Sabine MacCormack, David Lupher, and Andrew Laird. See S. MacCormack, *On the Wings of Time: Rome, the Incas, Spain, and Peru* (Princeton: Princeton University Press, 2007), 101; Lupher, *Romans in a New World*, 19ff; Andrew Laird, "Classical Culture in Colonial Mexico," in *The Epic of America: an Introduction to Rafael Landívar and the Rusticatio Mexicana*, ed. Andrew Laird (London: Duckworth, 2006), 11ff.

limited personal investment by subsequent viceroys; after the first two viceroys Mendoza and Velasco, the average viceroy lived in the city for 4 years before returning to Spain. Thus desagüe projects attempted to redress a sporadic problem with solutions that would outlast any single viceroy's term.⁵²

The path dependency of early investments in the city as the centre of government resulted in indecision about how to best remedy what seemed an insoluble problem. As Velasco reported in 1555: "If the rains return with the fury they have this year, the City is at stake...which cannot be avoided unless the city were moved and it is too late for that course of action...because the indigenous population would not support it."⁵³ However, if the rains were *not* extraordinary then the city's canals, dikes, and aqueducts all functioned.

In the late sixteenth century the Cuautitlán River, north of the city, was identified as the major source of rain water during city floods. The flood of 1553 allowed the city's inhabitants to use canoes inside the city, and as a result the viceroy conducted an inquiry into the rivers which poured into the Laguna. Because the Cuautitlán River—north of the Laguna—was the largest source of water, the second viceroy of New Spain, Luis de Velasco (senior, r. 1550-1564), designated parts of a swampy area to one side of the river as a floodplain. Velasco then assigned the royally appointed mayor of Atengo, García de Valverde, to prepare a dam and spillway from the river, instructing him that the disturbances to the native population in the neighboring towns be minimized.⁵⁴ In combination with raising the height of the Laguna's principal dam, the Albarradón de San Lázaro, and maintenance on the city's open canals, these changes to the water level were used to manage the waters with continuous adjustments for the next thirty years.

Flooding after intense summer rains in 1555 and 1556 resulted in further short-term adjustments to the city's aqueducts, dikes, and canals. In 1556 the city council (cabildo) began work on its first set of plans to redirect the Cuautitlán River and build more dikes. The city magistrates (regidores), however, denied the viceroy's requests to finance the city's water management activities. Velasco then wrote to

⁵² The Second Viceroy Luis de Velasco in a letter to Charles V (c.1555) expresses a pragmatic disapproval of Cortez's choice: "To my mind, it was a great error [of Cortez's] to have founded the city in this location because there were better sites only two or three leagues from here." Document included in Cadereyta's report on the desagüe. Cepeda and Carrillo, *Relación*, 20.

⁵³ Velasco reports to Charles V (c.1555) that the city will continue to be vulnerable unless some action is taken. *Ibid.*, 45-47.

⁵⁴ *Ibid.*, 44.

Charles V that the best option to prevent flooding required rerouting rivers in order to prevent the future damage to homes belonging to the populace, but work was begun on smaller rivers instead of the Cuautitlán. His letters of 1553 already identify the River Tula, further north, as a potential route for channeling and redirecting the waters of the valley, ultimately out to the Gulf of Mexico.⁵⁵

In 1579 a new flood afflicted the city's inhabitants. In response, Viceroy Martín Enríquez de Almanza attempted to manage the water problem by strengthening dikes, raising causeways, and unsilting canals. He also invited, for a site visit, the Basque architect Claudio Arciniega (c.1527-1593)—chief designer of the Cathedrals both in Mexico City and Puebla as well as various hospital and convent buildings—in addition to the city *corregidor* and members of the guild of *maestros*. In the environs of the Cuautitlán River, they took measurements from Molinos de Ontiveros following the route to the town of Huehuetoca through to Nochistongo and the River Tula—nearly 100km north of the capital. This committee concluded that it would indeed be possible to build canals that would connect three distinct rivers—the Cuautitlán, the Tula, and the Pánuco—which would ultimately drain Laguna rainwaters into the Gulf of Mexico. By this proposal the water runoff would travel at least 400km between the city and the sea in ideal circumstances. The viceroy instituted a weekly meeting at 3pm in his viceregal chamber anteroom for members of the committee and his council to discuss the potential consequences of the proposal.⁵⁶ While the plan was not enacted during Enriquez's term, it appears to be the origins of the project that Enrico Martínez oversaw twenty-seven years later in 1604.

In 1604, Viceroy Juan de Mendoza y Luna, Marqués de Montesclaros (r. 1603-1607) surveyed the elevations of Mexico City's northern suburbs with his advisors. Their objective was "to record useful measurements" of the most significant river system that drained into the lakes surrounding the island capital. The Cuautitlán River and its surrounding wetlands offered the committee insights about how to prevent future flooding in a city that was regularly below the fluctuating watertable. If not for the dikes, which cut across the lakes as retaining walls built by the Mexica in previous centuries, the city's marshland origins would reclaim it.

⁵⁵ Letter from Velasco to Charles V dates to 16 September 1555, text transcribed by Cepeda y Carrillo. *Ibid.*, 45.

⁵⁶ *Ibid.*

As Viceroy Mendoza y Luna surveyed, he held an open debate about the large-scale hydrologic management in the Valley of Mexico and welcomed proposals to resolve the city's unpredictable flooding. He called an emergency meeting of the Real Acuerdo and asked for a decision on the matter of a "perpetual [and] general" *desagüe*. Importantly the viceroy did not want the lakes to be emptied outright, but rather wanted the major source of exceptional rainwaters entering the Laguna—the Cuautitlán River—to bypass the lakes so that the city would not flood.⁵⁷ One proposal put forward concerned building a tunnel from Huehuetoca. This plan had been first proposed in the late 1570s, but Mendoza y Luna and the Audiencia as well as other governors, clerical and business representatives, and recordkeepers decided to reevaluate it and establish current measurements. They set sail from the Calzada de San Cristobal and again they re-measured the distance from the Molino de Ontiveros until they arrived at the Puente de Xaltocán, proceeding to the bend of the Laguna de Citlaltepec, calculating distances along the way. From there travel by water was no longer possible, and travel overland was complicated by swamps, hence they took surveyor's measurements using a quadrant to the village of Santa Maria de Atengo. From Atengo they continued overland to Huehuetoca, and then to the great hill near Tequisquiac. The distance was 52,218 *varas* (a *vara* is equal to approximately 0.75 metre, so 35km) and the height differential was 76 *varas* from the lake bed under the San Cristobal Bridge.⁵⁸

In response to the formal presentation of a proposed budget (1604) for the Huehuetoca Tunnel, Espinoza de la Plaza, one of the Crown's legal officers whose role it was to defend the interests of the realm and its native populations, put forth a variety of critiques and a more localized proposal for addressing the floods.⁵⁹ His

⁵⁷ Once the river was adequately diverted, it became clear that numerous other topographic features such as minor rivers filling the lakes and even the city's structural foundations could not be ignored.

⁵⁸ Cepeda and Carrillo, *Relación*, 48-49. Despite the topographical and toponymic changes over the last four centuries, the overland distances are still possible to check. According to Google Earth (accessed October 2015) the 52km appear generally accurate as does the approximate elevation differential between Huehuetoca and Tequisquiac. For an assessment of the reliability of Spanish measurements see Portuondo, "Lunar Eclipses," 249-76. Mexica surveyors also placed a high value on accurate measurements as demonstrated by their prehispanic land taxation records, see María del Carmen Jorge y Jorge et al., "Mathematical Accuracy of Aztec Land Surveys assessed from records in the Codex Vergara," *Proceedings of the National Academy of Sciences* 108, no. 37 (2011): 21.

⁵⁹ The official's title is "His Majesty's fiscal charged with matters of service to both the Crown and the Indigenous Peoples's Protection." In addition to Charles V's instructions to the early viceroys of New Spain to guard the indigenous peasants from exploitation, the first viceroy, Mendoza, left his successor a description of his own practices of listening to indigenous grievances. See Rubio Mañé, *Virrey popular*, 46-76; Mendoza, "Relación," 487. The Segunda Audiencia (1530) established a

critiques focused primarily on the number of indigenous workers who would need to leave their fields (or trades) in the villages in order to dig the channel. The budget proposed did not, in his rendering, consider the availability constraints of the labourers; no single labourer would be allowed, by royal limits on the *encomienda* system, to spend more than 3-4 weeks working on the project and so at least six new groups of workers would be required for a half year-long project. Espinoza argued that the requisite changeover of workers would disrupt the lives of a number of different indigenous communities and that this situation would be suboptimal. Next he pointed to the health and safety considerations not included in the budget proposal. Espinoza posited that the labourers would become ill or injured in the wet or exposed outdoor conditions of the Huehuetoca Tunnel project because they were neither in the habit of wearing much clothing nor likely to have access to the protective coverings that would keep them dry and allow them to move freely.⁶⁰ Persuaded by Espinoza's arguments in 1604, the viceroy's committee enacted his more modest suggestions for water management in the immediate area of the Laguna.⁶¹ Rather than undertaking the tunnel project, which would require large numbers of indigenous labourers, the viceregal councils opted for less disruptive measures.

legal system in New Spain that gave the indigenous population access to the viceroy, translators, and legal representation at court. This new structure of justice rather than simply imposing Spanish law upon the native population, incorporated indigenous legal procedures into Spanish structures and gave the peasants a right to bring a civil action to court, sue someone, or bring a grievance before a viceregal judge. Pre-colonial native law courts had, before this time, only been available to the elite, and local community leaders had handled all other disputes. Historian Medrano quotes Viceroy Mendoza indicating to his successor, Velasco, that as viceroy he would need to reserve time for the native peasants because "they are eager to have their cases heard." Wood's analysis of the artwork in early indigenous chronicles suggests that both viceroys, Mendoza and Velasco, were favourably portrayed in their role as judge. See, Wood, *Transcending*, 40-43; Ruiz Medrano, *Reshaping*, 76ff.

⁶⁰ Cepeda and Carrillo, *Relación*, 50-54. To support his stance against exposing indigenous workers to damp working conditions, Espinoza reminds his listeners of how plagues had previously threatened the population and invokes a recent royal mandate which stated that the viceroy desired the protection of *indios* from laboring in unfavourable environments such as mines "because preserving the life of a single *indio* is more valuable than all the riches of the Indies, as it is stated in your Royal Writ." Ibid., 51.

⁶¹ Espinoza supported the viceroy's on-going project to build more dikes with gates to adjust the flow and direction of floodwaters as well as adding floodgates to the existing Pre-Columbian dike, the Albarrada de San Lázaro. He also asserted that raising the height of the causeway of Guadalupe y San Cristobal to a height specified by the "geometers" would protect overland commercial traffic and pedestrian access. The canals which ran through the city appear not to have been unsilted as frequently as necessary; they are mentioned in the documents every so often. Ibid., 53-57. Chimalpahin mentions their cleaning on at least ten different occasions in particular in 1605 and 1614; nevertheless, the canal maintenance appears to have depended upon a special order from individual viceroys and included a call for short-term labourers rather than a steady workforce in waterworks maintenance. Chimalpahin Cuauhtlehuauhtzin, *Annals*, 85, 277.

The records produced by the 1580 and 1604 site visits are the earliest complete sets of documentation for a large-scale plan to change the hydrography of Mexico City by permanently rerouting its northernmost river flows. Flooding threatened all of the city's buildings, from ordinary homes and shops to palatial government offices, but baroque structures with intricate art or goldwork, such as churches, represented significant symbolic and financial investments and made them the focus of eyewitness flood accounts.

Flooded Buildings and the Beginnings of the Huehuetoca Tunnel

In 1596, when Florentine merchant Francesco Carletti's visited Mexico City during the dry months (November-March), he observed the residual effects of flooding.⁶² The city's architecture, he commented, was "built in the modern style by the Spaniards" with "houses of stone and lime, almost all of them with a sidewalk, along the straight, wide streets, wider even than those which Your Serene Highness has had made in the new Leghorn [Livorno, Italy]."⁶³ Carletti, impressed with the streets, appears to be suggesting the layout as a model for the Duke of Tuscany's renovation projects in Livorno when he says that Mexico City's streets "crossing one another, form very beautiful and perfect squares with three or four very ample and beautiful plazas and with fountains there and in places easily available to the public." He notes that the city is not without its architectural miscalculations, as a few of the earliest churches are sinking into the soft ground:

There are very beautiful churches and convents...which because of inadvertence on the part of the first founders of their [Augustinian] church, it is almost submerged to the height of a man, the foundation not having been placed on timbers, as it should have been... But it has not happened to that of the Society of Jesus, the Jesuits having arrived later and, using the experience of what had occurred to the others and joining it to their own shrewdness, having found a way to rest their building on timbers stuck into the water of the lake.⁶⁴

⁶² Carletti speaks highly of Mexico City at least thrice: "This is one of the most beautiful and one of the richest and most abounding regions possessed by the King of Spain, as it has every kind of native and foreign provision...the City of Mexico is an earthly paradise," Carletti, *Voyage*, 69. "I say that in this very beautiful city everything and every good is to be had in supreme perfection and abundance," *ibid.*, 59. "[The city is located] in a place as beautiful and delightful and abundant in every deliciousness as could be imagined or seen in the whole world," *ibid.* 57. Carletti indicated in his memoir that the veal in New Spain was fine and the pork was quite good and that the Spanish had succeeded in introducing all forms of domesticated animals as well as winemaking to the Americas. *Ibid.* 34-69.

⁶³ *Ibid.*, 58-59.

⁶⁴ *Ibid.*

The Augustinian church was likely still flooded from a previous rainy season rather than merely sinking. Carletti does not mention, or was not aware of, any flooding.⁶⁵

By contrast Chimalpahin, a long-time resident of the city, discussed at length how periodic flooding damaged the city's larger buildings. At the end of August in 1607 "the rains were very strong," he reports, "so that there was great flooding in Mexico City."⁶⁶ When the rains continued at the beginning of the following month, Chimalpahin notes that officials used pumps to bail out the church of Santo Domingo, "which was a sad sight; [inside] it was just a pond." Once pumped, the church floor was then raised.⁶⁷ For the months from May through October, Chimalpahin describes flooding in the four districts of the city except for the *plaza central*: "In absolutely all of Mexico-Tenochtitlan it was flooded everywhere. Only in the central part of the altepetl was a little land left that was not flooded." Boats were necessary to access homes across the city and "water entered the houses everywhere." Soon wooden bridges went up around the city, and walls served as paths and narrow roads for pedestrians. Some residents left the city for the countryside as the poorer homes, particularly those made from adobe, "were soaked at the base, so that they fell in." Only the market of Tlatelolco was not inundated; the others needed to close until the waters receded. The various religious orders held community prayer services and provided aid to the poor.⁶⁸

The severe flooding of 1607 during Luis de Velasco Junior's term as viceroy motivated a contest of engineering proposals to resolve the city's water issues once and for all. A variety of plans were submitted, differing primarily in their identification of a suitable area to redirect the waters. On 23 October 1607, the Junta approved Heinrich Martín's proposal to reroute the Cuautitlán River and connect it with the Tula River as well as to drain Lake Zumpango into the area of Nochistongo north of the city.

⁶⁵ Sinking colonial buildings were a great concern in late twentieth-century Mexico City. See, Eduardo Matos Moctezuma, "Arqueología urbana en el centro de la ciudad de México," in *Excavaciones del Programa de Arqueología Urbana*, ed. Eduardo Matos Moctezuma (México: INAH, 2003), 137.

⁶⁶ Cepeda and Carrillo, *Relación*, 67.

⁶⁷ Chimalpahin Cuauhtlehuanitzin, *Annals*, 101. He remarks that the church of San Agustín "was in good shape, because they had greatly raised the floor by filling it in two and a half years earlier." This may be the Augustinian church which Carletti noted a decade earlier.

⁶⁸ *Ibid.*

On 15 September 1607, Viceroy Luis de Velasco initiated preparations for digging a new water channel and tunnel near Huehuetoca.⁶⁹ First there was an open call in the city for workers of any ethnicity to help reroute river waters.⁷⁰ A large order for tools went out to the blacksmiths as well as an announcement that any designs of labour-saving machines for digging, lifting, and shifting earth would be rewarded according to their demonstrated utility at the work site.⁷¹ Next Velasco ordered a census of all available teams of oxen from surrounding towns belonging to both indigenous and Spanish agriculturalists because they would be useful for opening trenches. After a series of discussions with architects, city as well as royal officials and other advisors, including cosmographer-printer Enrico Martínez and painter-mapmaker Fray Andrés de la Concha, they settled on Nochistongo to begin the work because of its proximity and topography. At 11 am on 28 November 1607 a Mass took place at Nochistongo near the town of Huehuetoca to bless 1,500 workers and initiate the long-planned channel. Viceroy Luis de Velasco himself launched the work by “taking a few good hacks at the ground with a mattock.”⁷²

To resource the work and motivate workers, a budget had been proposed that paid each worker 8 reales per week (Table 3.2).⁷³ This budget was adjusted in 1607; rather than 8 reales per week, the labourers would in 1607 be paid 5 reales each week as well as a provision of food for daily meals. The fact that they might walk “3 leagues twice a day,” to and from Nochistongo, and that they could not be expected to walk home for a midday meal, is given as justification for the pay adjustment.⁷⁴ It is likely that workers took wives or female relatives with them to prepare and cook the meals in the same way that indigenous troops allied with the Spanish, in claiming other parts of New Spain, had always traveled with women to prepare meals.⁷⁵ The

⁶⁹ Cepeda and Carrillo, *Relación*, 48.

⁷⁰ The call went out to any unemployed labourer: mestizos, freed slaves, and any others who were not already contracted elsewhere. *Ibid.*, 67-68.

⁷¹ “Those who can design labour-saving methods or machines for the digging, extracting, and transporting of soil and stone of the *desagüe* should make their proposals that they may be paid according to the utility of their proposals” *ibid.*, 68. At least one of these successful labour-saving designs is mentioned, the *ingenio* (digging machine), was positioned in pairs at certain points and moved by draught animals. *Ibid.*, 73.

⁷² *Ibid.*, 69.

⁷³ The budget proposed in 1604 under Mendoza y Luna’s term was adapted under Velasco Junior’s second term (1607-1611) to replace three of the workers’ *reales* per week with a week’s worth of food staples.

⁷⁴ A league is an average distance that a person can walk in one hour. It is only a rough measure of distance as variations in terrain affect walking speed.

⁷⁵ The *Relación* does not indicate where the food is to be prepared or whether cooks were paid for their work, although it does mention the construction of temporary, multiuse structures, *jacales*.

food allotments consisted of: 1 pound meat and a bit over 3 pounds of corn per worker per day; as much *cal* (mineral lime) as needed for the preparation of the corn into *masa* for tortillas; a large bushel of dried chilies, grated, as well as 7 units of salt for every fifty workers per week; 40 *rajas* of firewood for every fifty workers per day; and two tools for grinding and cooking the corn shared by every fifty workers.⁷⁶ The meat and corn rations exceed 5,000 calories per person, per day, and seem reasonable for an eight hour day of digging or lifting.⁷⁷ In preparation for any injury or illness of the indigenous workers, the viceroy established a hospital in the town of Huehuetoca where medicines would be provided just as they were at the Hospital de los Convalecientes in Mexico City. Other desagüe employees included carpenters, brick makers and builders, engineers and supervisors.⁷⁸

Table 3.2: Desagüe Budget Proposal, 1604.

	Quantity	Pay per Week per Employee	Duration in Weeks	Subtotal
Labourers ⁷⁹	15,000	8 Reales*	24	360,000 Pesos*
Managers	300	100 Reales	24	90,000 Pesos
Supervisors	4	166.6 Reales	24	2,000 Pesos
		Cost per Unit		
Barretas Digging Rods	8,000	20 Reales		20,000 Pesos
Azadones / Mattocks	2,000	8 Reales		2,000 Pesos
Huacales / Crates	7,000	5 Reales		4,375 Pesos
Total:				478,375 Pesos

Source: “Parecer de los maestros sobre el desagüe” *Relación Universal de México 1637* (1976) p.50

*Note: 8 Reales converts to 1 Peso or ‘one silver-piece-of-eight’.

Regarding women cooks/homemakers who accompanied allied conquests, see Castañeda de la Paz, *Conflictos*, 375ff. Some of these women were warriors’ companions or *ahuianime*.

⁷⁶ Cepeda and Carrillo, *Relación*, 71.

⁷⁷ Assuming that the daily pound of meat is chicken (Chimalpahin mentions in his *Annals* that local taxes in 1595 were to be paid in poultry, *totolin*; Chimalpahin Cuauhtlehuanitzin, *Annals*, 53.) and also that the weekly supply of one *almud* of corn is its historical standard of a cubic decimetre—equivalent to 10 liters—then the daily ration is equivalent to about 1,000 calories from chicken plus 4,000 calories from corn per day. If a 59kg, 1.65metre tall, thirty-year-old male digs for seven hours using 470 calories per hour and then walks for 6 hours—totalling 4,730 calories—per day, then the food allotments would have met some workers’ full caloric needs each day. (The documents do not indicate how long the workday lasted but a six hour commute is assumed by the viceroy.)

⁷⁸ Cepeda and Carrillo, *Relación*, 72.

⁷⁹ Chimalpahin indicates that in 1593 one *real* bought one full basket of bread in Mexico City. Chimalpahin Cuauhtlehuanitzin, *Annals*, 51. That figure gives a concrete point of reference for the manual labourer's wage—according to this budget, workers would be paid 1.143 *reales* per day.

Figure 3.4: Lake Texcoco, c.1519

Building and Debating the Huehuetoca Tunnel

The Huehuetoca tunnel begun in 1607-1608 soon encountered two problems. First, the requisite capacity of the tunnel was underestimated: it was too narrow and not sufficiently steep in places to allow for the proper speed and quantity of water that it needed to channel. Moreover the domed roof did not facilitate regular cleaning of blockages caused by fallen branches and stones, and discouraged attempts to widen the channel. A second unexpected difficulty concerned the type of soil that the tunnel was dug into—*tepetate*. This crumbly ground was initially considered an aid to the project, praised for the ease with which it could be carved, but over time it proved to be unstable in places and, when it gave way, blocked the flow of water through the tunnel. Lacking local knowledge, techniques favoured by European engineers turned out to be unsuitable to the Valley of Mexico.

Between late November 1607 and late October 1608, after eleven months, 6.6 km of tunnel had been dug through soft, loamy soil.⁸⁰ The tunnel soon required reinforcement with a structure of arches which took another year and a half to complete. In a letter to King Philip III, Enrico Martínez's rivals, among them an engineer named Arias Alonso, critiqued the drainage project, saying that it had not solved the problem of flooding in the capital. The king's response implied that perhaps the situation required expertise of a different kind.

During Philip II's (1556-1598) and most of Philip III's (1598-1621) reigns, the viceroys of New Spain organized their own selection of engineers for urbanization in Mexico City. In 1614, however, the Crown in Madrid stepped in to address the seasonal floods as they had become a threat to the political stability of the capital: flood years were associated with popular unrest and short-term inflation. In the interest of funding expertise, the Spanish Crown functioned in some ways as an equal opportunity employer, calling on engineering experts from among Protestant as well as Catholic specialists. Immigration records indicate that more than 200 mining engineers from a variety of countries moved to Spain during the sixteenth century and many of those proceeded to New Spain.⁸¹ Only a few were employed in the *desagüe* project; many more worked in gold and silver mines. But within a century of Spanish colonization, there was no dearth of skilled personnel in New Spain; European engineers migrated to Spain in order to cross the Atlantic with significant posts.⁸² Whether draining lakes or draining mines, they shared a common understanding of hydraulics and a basic set of tools: the mill, the pulley, and the pump.⁸³ They also

⁸⁰ By 1651, the drainage workers used gunpowder to blast the Huehuetoca tunnel through hills. The clergyman-secretary Gregorio de Guijo (d. 1666) gives an account of gunpowder blasting to aid the *desagüe*: "From Wednesday 18-Tuesday 27 February 1651 the viceroy Luis Enríquez de Guzmán, Conde Alba de Liste and a *gobernador* visited the Huehuetoca drainage sites in order to blast a hill which obstructed the work and for this purpose they took with them many hundredweights of gunpowder"; Gregorio De Guijo, *Diario 1648-1664* (México: Porrúa, 1986), 148. The sale and price of saltpeter in Mexico City was strictly regulated by the viceregal government to limit its use. In 1604 Cristóbal Gudiel, the official licenced vendor of gunpowder, *armero-polvorista real* wrote that the prices were at 3-5 *reales* per pound depending on the type. AGI., México, 27, N.18. *Cartas del Virrey Marqués de Montesclaros (1603-1607)*. See Rodríguez-Sala, *Eclipse*, 90. The Crown's system of gunpowder licensing was known as *arrendamiento*; see Covadonga Villar Ortiz, *La renta de la pólvora en Nueva España, 1569-1767* (Sevilla: Escuela de Estudios Hispano-Americanos, 1988), 29-45.

⁸¹ Julio Sánchez Gómez, *La savia del imperio: tres estudios de economía colonial* (Salamanca: Universidad de Salamanca, 1997), 82-83.

⁸² Moncada Maya has identified four Dutch and German military engineers directing the construction of seventeenth-century New Spain's forts: Adrian Boot, Jaime Franck, Marcus Lucius, and Martín "de la Torre" in *Ingenieros*, 20-27.

⁸³ The use of mine pumps in the *desagüe* is explicitly discussed in 1608: see Cepeda and Carrillo, *Relación*, 87. For an early eighteenth-century discussion of the mechanisms of mine drainage,

took advantage of new tools, including new machines for pumping ships, mines, and waterways,⁸⁴ and carried books written about them.⁸⁵

In 1614, Adrian Boot, a Dutch hydraulic engineer with extensive experience in water management, arrived by the King's commission in Mexico City to evaluate the works and recommend alternative solutions. Once in Mexico City, Boot enjoyed the luxury of the vice-regal court and toured the pyramids and monuments. He would have seen Puebla's famous cathedral and *parián* or plaza, the glassworks and Chinese potters' district, visited the convent confectionary shops, and perhaps stopped to see the pyramid of Cholula nearby. On his journey he carried with him an extensive collection of books.

Adrian Boot's book collection identifies a new set of mathematical and scientific books present in Mexico City during the seventeenth century.⁸⁶ While the precise repositories of his library are currently unknown, the books he took to New Spain represented contemporary European texts available in engineering and were likely absorbed by the best library collections of Mexico City.⁸⁷ Additionally, during

Juan Antonio de Mendoza y González's "De los Arbitrios para Desaguar Minas" (Imprenta de José Bernardo de Hogal, México, 1727) synthesizes contemporary thought and local practices; cited in Trabulse, *Historia*, 353-61.

⁸⁴ Little scholarship exists on crane design for construction purposes in the Americas although it was the most significant technology of the colonial city. Juan de Herrera's sixteenth-century designs for construction cranes and iron cutters have been published recently as manuscript facsimiles with adjoining commentary and transcription. See Luis Cervera Vera, *El 'ingenio' creado por Juan de Herrera para cortar hierro* (Madrid: Castalia, 1972), 13-14; Juan de Herrera and Luis Cervera Vera, *El manuscrito de Juan de Herrera indebidamente titulado Architettura y Machinas* (Valencia: Patrimonio, 1996), 31; Luis Cervera Vera, "Transcripción del manuscrito autógrafo de Juan de Herrera sobre la teoría matemática de las grúas " *Archivo español de arte* 70, no. 277 (1997): 73ff. Also see: María Luisa Rodríguez-Sala, "Tres Constructores de Obras Científico-Técnicas de Minería y Metalurgia en la Nueva España del Siglo XVII: Luis Berrio de Montalvo, Jerónimo de Becerra y Juan del Corro," *Anuario de Estudios Americanos* 57, no. 2 (2000): 631-59.

⁸⁵ Barrera-Osorio, *Experiencing Nature*, Appendix 2, tables 4-8; José Cervera Jiménez, "Ciencia Europea en las colonias españolas de América: los libros de matemáticas y astronomía en la Nueva España," in *Libros y lectores en la Nueva España*, ed. Blanca López de Mariscal (Monterrey: Instituto de Estudios Superiores, 2005), 161.

⁸⁶ Adrian Boot's book inventory identifies a new set of mathematical and scientific books present in Mexico City during the seventeenth century; while Boot is known to historians, his book inventory has not yet been published. Out of a total of 240 books inventoried, the Inquisition suspected two of being Lutheran, vernacular, bibles. As Protestant translations of scripture, the Inquisition declared them "marginalizados." Boot's other books were not commented upon by the censors. Forty-five titles appear to have served as references for workaday matters of engineers. The vast majority of his books appear to have been pleasure reading such as romances with a small part related to prayer. The engineer also owned numerous biographies.

Based on the printers and publication cities, roughly box #1 of his books contained the works Boot acquired while travelling to New Spain and box #2, the works he had owned for a longer time. His collection of books indicates what he imagined would be useful and may suggest that he was migrating rather than simply taking a short-term position.

⁸⁷ Leonard has argued that Baroque literary culture and book collections in Mexico City outstripped those found elsewhere in the Americas at the same time, see Leonard, *Baroque*, 166. The

his residence in Mexico City,⁸⁸ Boot published a work on hydraulic engineering with Martínez's press entitled *Informe sobre el desagüe de las Lagunas de México y obras de Enrico Martín, por Adrian Bo[o]t* (México, 1637).⁸⁹ At least 17% of the books with which he crossed the Atlantic addressed architecture and mathematics, and the remaining were romances, biographies, and histories for pleasure reading. Two religious works, a Protestant Bible and a Catholic prayer book, appear to be the cause of the Mexican Inquisition's interest in Boot although the case may have been dismissed as no other evidence of a prosecution exists.⁹⁰

Table 3.3: Selection from Adrian Boot's Library, 17 September 1637⁹¹

1. Martín Savatianiis Sergio (Bolonense), *Arquitectura*. En italiano. Pedro Denicolionide: Amalfia, 1551.
2. Leon Baptista Alberti, trans. Bartolome Cosimo (Florentino), *Arquitectura*. En lengua florentina. Leonardo Torrentino: Ermonte Regali, 1565.
3. Capitán Cristóbal de Rojas (Ingeniero del Reino), *Geométrica y Matemática de Fortificaciones*. Madrid, 1598.
4. *Relación Universal Legítima y Verdadera del Sitio en que Está Fundada la Ciudad*. Francisco Salvago: 1637.
5. *De la Architectura*. En italiano. Antonio Rusconi: Venezia, 1590.

writings and book collections of engineers offer insights about their role as intellectuals in a colonial society and can suggest their approaches to mechanical problem solving. They migrated to the New World with their respective expertise and possessions—many of which were tools for sharing with collaborators and assets for potential exchange. As possessors of training in diverse European settings, Andrés, Boot, and Martínez made their approaches to the desagüe more distinct and contradictory than perhaps the Crown and viceroy had in mind. Nevertheless the procedure was a rational one, an open call for solutions to a large-scale problem wherein creative and divergent solutions were collected and recorded. Their book collections illuminate the intellectual playing field of the technical communities within which they worked. Boot's books portray a Scientific Revolution in slow-motion with their focus on mechanization and mathematics while including works specifically for entertainment as well as religious practice. Meanwhile Andrés' focused technical writings and Martínez's work of popular science, *Repertorio*, portray the implications of an engineer's insights for the colonial world in which they lived.

⁸⁸ Very little is known about Boot's later life. David Marley argues that Boot lost political support in Mexico City after a series of engineering failures and was suspected of strategic incompetence. The Inquisition placed Boot in a monastery as a form of house-arrest and was given his own books to read. See David Marley, "Adrian Boot, a Dutch Engineer in Colonial New Spain (1614-1637)," *Canadian Journal of Netherlandic Studies* 4, no. ii (1983): 74-77.

⁸⁹ While at least one copy existed in the early nineteenth century when bibliographer José Mariano Beristáin y Souza (1756-1817) recorded it in his *Biblioteca Hispano-Americana Septentrional* (Mexico City, 1816), extant copies of Boot's *Informe* have not yet been found; see A.S. Wilkinson and A.U. Lorenzo, *Iberian Books Volumes II & III: Books published in Spain, Portugal and the New World or elsewhere in Spanish or Portuguese between 1601 and 1650* (Leiden: Brill, 2015), entry 22897, page 160.

⁹⁰ See note 86. On the circulation of Protestant Bibles in early colonial New Spain, see Nora Edith Jiménez, "La Biblia de Vatablo entre Europa y la Nueva España en el siglo XVI," in *Del autor al lector: libros y libreros en la historia*, eds. Carmen Castañeda García, et al. (México: Investigaciones Superiores en Antropología Social, 2002), 135-61.

⁹¹ My transcription and selection from the archival document: México Archivo General de la Nación, "Inventario de los libros que están en el baul de... Adrian Boot, 1637," (Instituciones Coloniales: Inquisición 12213, Vol 383, Expediente 10).

6. *Tratado de Matemáticas de Moya*. Luis Gracián: Alcalá de Henares, 1573.
7. Clavito Delfán [...], *Reglas Militares de su [...]*. En italiano. Aquino Dionesio: Amberes, 1611.
8. Domingo Fontana (Arquitecto de su Santidad), *De la Transportatione de Obelisco Vaticano y de la Fábrica de Papa [...]* Quinto. Domingo Basa: Roma, 1590.
9. *Teatro de las Principales Ciudades del Mundo*. En latín. Colonia Agripina, 1617.
10. Guillermo Bou[...] (Presidente del Delfín), *Discurso de la Disciplina Militar de los Romanos*. En italiano. Guillermo Robili: León, 1595.
11. Jacobi Besoni de Fromatis (Matemático), *Teatro Instrumentorum ed Maquinarum*. En latín. Bartolomé Binsensi: León, 1578.
12. *Guidiubaldi et maquionibus montis prespetivi*. En latín. Geronimi Concordian: Pisa, 1600.
13. Gierolamo Catano (Navarese), *Nuevas Obras de Fortificaciones para Ofender y Defender*. En italiano. Giobattista Bosola: Grecia, 1564.
14. Leon Bautista Alberto, *Los Diez Libros de Arquitectura*. En romance. Galense Gómez (Impresor de su Magestad): Madrid, 1582.
15. Abraham y Goreli Antwerpiani, *Del Uso de los Añillos y Sibilos Sacados en Hierro, Plata, y Oro*. En latín. Abraham y Goreli: Lugduni (Bataborun), 1619.
16. González de Medina Garva (natural de Burgos), *Examen de Fortificación*. En romance. Lugares Teatro: Madrid, 1599.
17. Liesur de Furance Riubarut, *La técnica de la Artillería*. En francés. Adrian Senes [&] Ruis Sanz Jacques: Paris, 1605.
18. Pedro Apian y Moreso (en Amberes), *De la Cosmografía de Pedro Apian y Moreso en Amberes*. En romance. Casa de Gregorio Gensio: Basilea, 1548.
19. *Lechuga de Artillerías*. [s.f., s.n.]
20. Jorge Agrícola, De minas y metales, primer libro. En alemán. Francfortia, 1580.
- 20a. Felipe Bochio (filósofo y médico), “Otro añadido.” En latín y alemán. Universidad de Basilea.
21. Jacome de Bienola, *Reglas Generales de las Cinco Ordenes de Arquitectura*. Traducido de Toscano en Roma por Patricio Cagerij. Madrid: 1593.
22. Guillermo Juan San Blas, *El Peso Marítimo* contiene “Enseñanza del arte de marear y descripción de las costas marítimas de las mares.” En flamenco. Amsterdam, 1627.
23. Apiano y otros autores excelentes juntado por S. D. Z. B. *De astrología, y astronomía*. En flamenco. Abraham Vilyr (mercador de libros): Res. Alan Arnode, 1608.
24. Antonio [...] *De Architectura. Dirigido al Duque de Florencia*. Deluxe binding.
25. Vitrubio, traducido por Daniel Barzzo de Aquilea. *Los Diez Libros de Architectura de [...]* Vitrubio. En italiano. Francisco de Francesi Senes: Venecia, 1584.
26. [s.n.], “Con muchas cartas de Mareas impresas de diversas partes del mundo.” En flamenco. Amsterdam, [s.f.].
27. Simón Stubin Debrugia, *Principios del Arte de Peso y Medidas*. En flamenco. Francisco de Ratelin: Leiden, 1586.
28. [s.n.], *La Tienda de Oro de los Amadores de las Ciencias Flamencas*. En flamenco. R[...]: Amsterdam, 1613.
29. [s.n.], *De Fortificación*. En flamenco. Francisco Rebelingue: Leiden, 1594.
30. Miguel Lunet, *Marinería el arte de la Navegación*. En flamenco. Cornelius Clasen: Amsterdam, 1598.
31. Antonio Rusconi, *De la Architectura. Con Estampas*. En italiano. Elario della [...]: Venecia, [s.f.]. Folio.
32. Juan Beguín, *Los elementos del Arte Química*. En francés. Mateo de Maestre: Paris, 1620.
33. Guillermo Clumy, *Practica Provechosa para los Cirujanos*. En inglés. Tomás Urbin: [s.l.], 1591.
34. Vandenbuek, *Instrucción del arte de Marear por todo el Mundo*. Abraham Migons: Rotterdam, 1610.
35. Claudio Flamant, *Guía de Fortificaciones*. En francés. Jacques Foillet: Mont Bellart, 1597.
36. [s.n.] *Tesoro de las Cartas que Contienen las Mapas de todo el Mundo*. En flamenco. Midleburg: Bart Lang[.], 1598.

37. Rabaut, *El Cirujano Executor*. En francés. Leon, 1633.
38. [s.n.], *Cristiana Navegación Marítima*. En flamenco. [s.f.]
39. [s.n.], *De Artillería*. En flamenco. Francoforte, 1590.
- 39a. [s.n.], "Otro cuaderno. Trata de lo mismo." Cristian Egenol[...]: Frankfort, 1536.
40. Jorge Braum, Simón Nobelanus, y Francisco Gosenberg, *Descripción de todas las Ciudades más Principales del Mundo*. En alemán. Godfredo Campo: Cologne, 1582. 5
41. Guillermo Blau, *De la Declinación del Sol*. En flamenco. Guillermo Blau: Amsterdam, 1525.
42. [s.n.], *Recetas Secretas*. Beneto Rugaut: Leon, 1574.
43. [s.n.], *El Tesoro de los Secretarios*. En francés. Osmont: Rouen, 1597.
44. [s.n.], *Nuevos Instrumentos* En alemán. Ludovico Comies: Basilea, 1607.
45. Martin Abraham [l'Écossais], *De Cosmografía*. En latín. Manuscript. [ca.1600]
46. Aemilo Agrippa, *Tratado de transporter el agua de San Pedro*. En italiano. Francisco Janet: Roma, 1583.
47. [s.n.], *Calendario de los Pastores*. En flamenco. Enrique Garens: Amsterdam, 1614.

Source: Archivo General de la Nación, México. Instituciones Coloniales: Inquisición 12213, Vol 383, Expediente 10. "Inventario de Adrian Boot, 1637."

Of the forty-seven titles that likely served as references for the workaday matters of engineers, 6% were on mathematics, 21% on architecture & cities, 13% about forts, 17% concerning artillery and machines, and 4% on aqueducts; cartography (8%), navigation (8%), astronomy & calendars (6%), metals and chemistry (8%), surgery (4%), one book of "Flemish Sciences," and one guide to formal epistolary because reports to patrons and dignitaries were part of his skillset.

Boot proposed opening up five new canals and mechanically pumping the lake waters away from the city. He saw the hydraulic methods of his Flemish homeland as the answer to living sustainably upon the waters in the Valley of Mexico.⁹² Boot's proposal had in common with the sustainable practices of the amphibious city's past a regular responsiveness to the ebb and flow of water, and to a large degree, daily maintenance, as it was done in his homeland, Flanders.

The viceroy Diego Fernández de Córdoba, Marqués de Guadalcázar, however, did not favour Boot's proposal. The plan to encircle Mexico City with pumps and add more dikes seemed less feasible than the proposals that he had considered already. Without easy access to the ocean, the pumped lakewaters would still need to be transported to some sort of reservoir, since Mexico City lies approximately 250 mountainous kilometres from either coast. The proposed budget and regular maintenance costs—as the pumps would require constant vigilance—also discouraged the viceroy. The viceroy's council must have wondered whether the waters would not

⁹² John López, "In the Art of My Profession': Adrian Boot and Dutch Water Management in Colonial Mexico City," *Journal of Latin American Geography* 11, no. 2 (2012): 35-60.

simply build up outside the proposed dikes, ever-pulled towards the capital's low ground. The plan just did not seem practicable.⁹³ Engineer Enrico Martínez was thus again selected to continue directing the Huehuetoca Canal.

In 1623 the next viceroy, Diego Carrillo Mendoza Pimentel, again consulted with a series of engineers and technicians, including Galdo de Guzmán, Simón Enríquez, Enrico Martínez, Adrian Boot, Jerónimo Farfán and Francisco Ruano, on the matter of the desagüe. Unconvinced that the project was necessary and unsatisfied with the contradictory advice that his collection of experts had to offer, the viceroy decided to start from scratch. Removing the floodgates that Martínez had built in the Cuautitlán River, the new viceroy sought to measure the unhampered seasonal water levels systematically and use those measurements for the design of an effective water management programme. But instead he initiated a disastrous six year period of floods worse than any other on record, and his popular support plummeted. Meanwhile, Martínez was imprisoned under accusations of malfeasance and released after three days of intense rains in the hopes that he could channel the flow of the Cuautitlán River. Thus, in 1624, when viceroy Diego Carrillo Mendoza Pimentel deposed the Archbishop of Mexico City, Juan Perez de la Serna, and ordered him sent back to Spain after a series of disputes about the cleric's susceptibility to bribes, the confused populace rose up against the viceroy and chased him out of the city.⁹⁴

Philip IV pardoned the rioters who drove Viceroy Pimentel out of the capital in 1627, concluding that the viceroy was in part to blame for the upset.⁹⁵ Pimentel's efforts were well-intentioned and in many ways perspicacious. Nevertheless, his early unwillingness to rescind his drastic order to disable the floodgates proved to be a grave political and administrative error. It not only made him lose face but lost him the support of the entrepreneurial class and poor alike—both groups suffered in the flooding.

Each inundation of the city interrupted its economic activity and sometimes resulted in famine or civil unrest. In response, Rodrigo Pacheco y Osorio, 3rd Marquis of Cerralvo, viceroy from November 3, 1624 to September 16, 1635, ordered that the city be shifted to Tacubaya on 19 May 1630. The guilds opposed his proposal, and the city was not moved. Philip IV had selected him to report on the rioting during the

⁹³ Hoberman, "Technological Change," 631-59.

⁹⁴ Manuel García Purón, *México y sus gobernantes, biografías* (México: Porrúa, 1964), 82-83.

⁹⁵ Gibrán Bautista y Lugo, "Cédulas del perdón real a los rebeldes de la ciudad de México, 1627," *Estudios de Historia Novohispana*, no. 52: 68-74.

previous viceroy's term. Rodrigo Pacheco organized a comprehensive history of the desagüe project, *Relación Universal de 1637*, continued under the next viceroy, Lope Díez de Armendáriz, Marqués de Cadereyta (in office from 1635 to 1640).

In 1630, Martínez continued work on the channel to Huehuetoca and took up Simón Mendez's proposal to establish a new channel another 20 km north to Tequixquiac. Martínez died in 1632, long before this extension was finished but nevertheless completed 5.87 kilometres of the Huehuetoca channel. Viceroy Lope Díez Armendáriz' *Relación* dated 6 December 1641 states that after the great flood prompted by Carrillo Mendoza Pimentel, he initiated remedial debris cleanup of the canals and irrigation ditches to good effect of trade and the flow of canoe traffic.⁹⁶

After Martínez's death in 1632, Viceroy Armendáriz assigned a Carmelite friar, Fray Andrés de San Miguel (1577-1644), born Andrés de Segura de la Alcuña, an architect from Medina-Sidonia in southern Spain, to assess the state of the canals in Mexico City and propose a budget for continued maintenance.⁹⁷ Fray Andrés wrote Viceroy Armendáriz a letter about his findings and recommendations. In his letter, he critiques Enrico Martínez's inexperience with hydraulic engineering and presents his own proposals for correcting Martínez's work by widening the canals in strategic locations. His first recommendation is that a qualified "maestro," or overseer, be put in charge, someone who is "diligent, knowledgeable, hale and healthy so that he can personally take part in the greatest and most difficult labours."⁹⁸ It matters less to Fray Andrés that the maestro be schooled in architecture than that the person have experience near water; Fray Andrés seems to be recommending someone similar to himself: full of vigour and vim and younger in appearance than his fifty-five years.⁹⁹ Fray Andrés proceeds then to outline the steps to recover and continue the city's water management plan. At one point he cleverly describes an approach which would, at

⁹⁶ "Díez writes to King Philip III" Marqués de Cadereyta Lope Díez de Armendáriz, "Relación del estado en que dejó el gobierno de Lope Díez..." in *Los virreyes españoles en América durante el gobierno de la casa de Austria*, eds. Lewis Hanke, et al. (Madrid: Atlas, 1977), vol 4, 10-17.

⁹⁷ Fray Andrés was a skilled draftsman as well as an architect, and he recorded many of the Mozarabic designs he witnessed in southern Spain. See: Enrique Nuere, *La carpintería de lazo: lectura dibujada del manuscrito de Fray Andrés de San Miguel* (Málaga: Delegación de Málaga, 1990); Manuel Toussaint, "Fray Andrés de San Miguel, Arquitecto de la Nueva España," *Anales del Instituto de Investigaciones Estéticas* 4, no. 13 (2012 [1948]): 5-25.

⁹⁸ Fray Andrés de San Miguel and José de Agreda y Sánchez, "Informe inédito dado en 1636 al virrey Marques de Cadereyta acerca del desagüe de Huehuetoca," *Anales del Museo Nacional* IV, no. 35 (1890): 180.

⁹⁹ Ibid. Fray Andrés critiqued Martínez roundly by saying that Martínez was not so much to blame for his lack of experience with hydraulic engineering as was "the person who hired an astrologer to supervise the desagüe!": see *ibid.*, 177.

least in theory, result in a “self-healing” canal where “the water itself will further deepen the canal and clear out any loose soil.”¹⁰⁰ Stating the distances between key sections of the tunnel and canals, Fray Andrés provides evidence of a thoroughly planned set of solutions. He includes a discussion of the hydraulic forces in action—by comparing certain aspects of the project to the estuary dynamics of the Guadalquivir in Seville—that would have been more familiar to his audience most of whom embarked at the major Spanish port city before arriving in Mexico City.

Drawing upon his own first-hand experience in Seville, Fray Andrés explains the flow of river water into the sea, the Guadalquivir and the Mediterranean Sea, and how the countervailing force of even mild waves from the sea and the depth of the river bed interact to determine the overall direction of water flows there. He explains that in the case of the “laguna de México” and its relatively new drainage channels, the depth of those channels were insufficient and not working as Martínez had planned. Fray Andrés attributes these planning errors to Martínez’s lack of familiarity with hydraulics: “despite his great skill with mathematics,” Fray Andrés states that Martínez lacked knowledge of the nature of water and its currents.¹⁰¹ With regards to the San Gregorio River, Fray Andrés recommends that a shiftable lock be installed that would be moved along the canal to strategic locations as the weather required.¹⁰² He also specifies the number of *varas* that the channels need to be deepened and widened in order to function optimally. Thinking about future maintenance, Fray Andrés proposes dedicating the city council’s road repair budget to raising the main roads to four times their current height in order to ensure access in and out of the city during times of flood. Continuing with the logistics, he predicts that two men would be sufficient to stand sentry at each main road during the rainy periods and direct labourers who repair crumbled banks. He asserts that these changes were needed to preserve the fishing and irrigation waters of the lakes Chalco and Mexicalcingo that have always benefitted the city.¹⁰³ This introduction concludes with the distances of

¹⁰⁰ Ibid., 181.

¹⁰¹ Ibid., 182. Despite Fray Andrés’ low estimation of Martínez’s hydraulic engineering skills, Martínez’s report to the viceroy Marqués de Cerralvo in 1628 on the desagüe demonstrates a clear vision of what steps were yet to be completed toward the goal of closing off the Laguna from seasonal floods by rerouting the Cuautitlán River. Enrico Martínez, “Relación de Enrico Martínez, año de 1628” in *Relaciones del desagüe del Valle de México, años de 1555-1823* (México: Secretaría de Obras Públicas, 1976), 27-37.

¹⁰² San Miguel and Agreda y Sánchez, “Informe,” 184.

¹⁰³ Ibid., 185.

each section followed by a labour and equipment budget which he argues is lower than that of raising the ground level of the entire city.

Within a postscript to his report of 1636, Fray Andrés, an experienced architect of aqueducts and monasteries, reasserts that the tunnel requires the skills of surveying for a measured and an even slope, as faults in this regard “have caused so many needless costs and delays.”¹⁰⁴ In Fray Andrés’ assessment, the height of the walls varied in unsystematic ways and showed a lack of correct levelling. Based upon the observations from his most recent visit to the tunnel and canals, Fray Andrés confirms the viability of his previous recommendations and adds a more technical analysis of the errors to be avoided in the furthering of the water works. He describes how parts of the tunnel collapsed in the flood of 1629 in part because the tunnel walls are made of *tepetate* which crumbles with time. Fray Andrés says that in one year’s time the wood and brick used to support the arches of the tunnel have suffered or given way because they cannot support the water pressure. Fray Andrés then suggests a reversal of the current weight distribution by stating that the arch supports need to be made vertical.¹⁰⁵ And he states that Martínez has already made “all errors that were possible” while directing the desagüe project.¹⁰⁶

In January of 1637, Fray Andrés along with Boot, Puebla architect and mapmaker Juan Gómez de Trasmonte, foreman Juan Serrano, and lawyer Don Juan de Burgos, took new measurements of the shifting banks of the desagüe canals at the request of Viceroy Marqués de Cadereita. During this examination of the desagüe sites, Adrian Boot said that “in France and Flanders as well as in other places water is used to move and collect land” and also that “the force of the water itself ought to be harnessed for widening the desagüe.”¹⁰⁷ Boot’s comment based on his prior experience with hydraulics elsewhere seems to offer a valuable labour-saving principle; if only he had been able to communicate to his colleagues on the viceroy’s committee a persuasive application of the general principle.

What emerges from the available documentation appears to be a series of proposals by engineers, made from 1606 to 1640, seeking to be contracted by the

¹⁰⁴ Ibid., 188.

¹⁰⁵ Ibid., 191.

¹⁰⁶ Ibid., 177.

¹⁰⁷ Ibid., 191.

viceroy's committee.¹⁰⁸ The viceroy was largely hamstrung by the arguments of the Real Audiencia, whose role it was to uphold Spanish law by representing the interests of the indigenous workers and the concerns of the business sector represented by the municipal council. As certain problems like the crumbling *tepetate* could not have been known in advance and the engineers with the best ideas were not necessarily the best at pitching them persuasively to the viceregal committee members, it was not obvious in which hydraulic "experiments" to invest the capital's resources. Enrico Martínez had been contracted in 1607 in part because his budget was smaller than his rival's but mostly because he knew how to speak to the businessmen on the city council.¹⁰⁹ As a German emigré, a mathematician-astronomer, a published author, a successful owner of a printing business, an associate of the Inquisition, and a cosmographer-hydraulic engineer for the viceroy, Martínez seems to have been skilled at knowing how to tap the social networks of Mexico City. His vitality persuaded the committee that he understood the problem of the *desagüe* thoroughly enough to resolve it.

Martínez, Fray Andrés, and Boot used mutually-exclusive paradigms for assessing the waterworks and disagreed with others' proposals, but their willingness,

¹⁰⁸ The oft-repeated story in the historiography is that a minor melodrama delayed the *desagüe*'s progress—a competition between the contractors Martínez and Boot. Boot, hired by the Crown in Madrid, held a position of higher pay and greater authority when he arrived in Mexico City and sparked Martínez's ire. Holding a post with the local office of the Inquisition made Martínez an intelligence agent of sorts and when it suited his purposes, the story goes, he accused Boot of owning Protestant religious books. There are a few non sequiturs in this narrative. Boot's books were confiscated by the Mexican Inquisition five years after Martínez's death; Martínez had been congenial enough during his lifetime to publish Boot's publication on the *desagüe* project; and Boot does not appear to have wasted any time on competing with Martínez in the city since Boot was engaged as a military engineer designing the forts at Veracruz and Acapulco. The difficulties of the *desagüe* project were more complex than a story about rivalry can explain.

¹⁰⁹ A statue of Enrico Martínez stands beside the Cathedral in the central square of Mexico City today. He was born Heinrich Martín in Hamburg (c.1555-1632) and migrated with his family as an eight year old to Seville. In 1589 he traveled to New Spain and settled in Mexico City as a versatile member of the local professional community. His *Repertorio de los Tiempos e Historia Natural de la Nueva España* (1604) was cited by Chimalpahin and published by the author's own press. (Chimalpahin translated parts of Enrico Martínez's *Repertorio... 1604* into Nahuatl for a section of *Annals*.) In the *Repertorio*, Martínez includes his accounts of life in New Spain supplemented by an almanaque and astrological report. A notable aspect of the work is Martínez's discourse on what constitutes "science for the masses." Martínez structures his work with a description of the universe in Book 1 and in successive books systematically narrows its focus to descriptions of New Spain, and finally widens out again to a chronicle of historical events in Castile and the rest of the world including the eastern Mediterranean. (Chimalpahin references the European current-events section of the text. Gruzinski discusses the same section of Martínez's work in a different context, see Serge Gruzinski, *What time is it there? America and Islam at the dawn of modern times* (Cambridge: Polity Press, 2010), 64-85.) Leonardo Abraham González Morales, "Enrico Martínez y el primer *desagüe* artificial de la Nueva España" (MA Thesis, UNAM, 2011), 357ff; Enrico Martínez, *Repertorio de los tiempos e historia natural de esta Nueva España*, eds. Francisco González de Cossío, et al. (México: Condumex, 1991 [1606]).

on multiple occasions, to participate in the collaborative process of assessing the worksite with colleagues and reporting to the viceroy displays a genuine desire to successfully solve the problem of flooding. Fray Andrés' concrete proposals, and Boot's more general principals, appear to have been missed opportunities to improve Mexico City's waterworks project. Thus the presence of adequate engineering skill and human capital did not in this case coincide with timely access to official funding and support. If the viceroy's committee of advisors had fully understood the long-term costs of Martínez's expedient methods, perhaps the insights of engineers like Fray Andrés and Boot could have been tapped sooner. Whether the viceroy's advisors held short-term posts that changed with the incoming viceroys or were long-term city residents likely impacted their decisions to support short-term or long-term redevelopment. The concern that indigenous labourers not be misused also loomed large in the discussions.

Conclusion

This case study of the *desagüe*, 1606-1640 adds another facet for examining scientific practices in the early modern Spanish Americas. The problem of the city's drainage was larger than just civil engineering; it was an assimilation of the city to European architecture, modes of transportation, food production, and religious observance. A transformation of the city's topography, 1519-1640, was a fulcrum in the process of acculturation. The symbolic weight of change met the everyday needs of a burgeoning imperial *entrêpot*, and the difficulties of topography were distinct from those known in Europe, and thus exceeded available resources for another century and a half.

What emerges as distinct in this account is the complexity of the process by which successive viceroys and city council members continuously adjusted the city and surrounding countryside's hydraulic maintenance to lessen the impact of rising water levels upon the city. But geography appears to have been less of a constraint during the first fifty years of adapting to the floods than the Crown's mandate to protect the indigenous population. Indigenous governors and royally appointed Spanish officials alike lobbied to reduce large scale impositions upon native farmers and peasants. Until 1607, rather than divert large numbers of villagers and farmers from their self-directed cycles of work, the viceregal councils chose—on more than

one occasion—to concentrate on those smaller hydraulic projects which inconvenienced the villagers less but ultimately postponed necessary undertakings.

This chapter examined a tightly-knit community of Spanish, Dutch, and German engineers in Mexico City to identify how scientific knowledge informed their collaboration. Their books and writings illustrate the Scientific Revolution in slow-motion: Vitruvius' and Alberti's machinery complemented Aristotle's physics. Mexico City was a laboratory where scientists experimented under the auspices of the state, and while the state protected its commercial interests in the colonies it also sought the expertise of specialists. The nature of debate, publication, and the reception of ideas within a professional community in Mexico City also will be considered in the following chapter, which in examining the dynamics of the *criollo* (locally-educated) scientific community, will identify its networks and the impact of the Inquisition as a gatekeeper.

Chapter 4 Astronomy and Optical Instruments in Mexico City- Puebla: Scientific Networks in Spanish America & Europe (1611- 1692)

The moon passed slowly in front of the morning sun at quarter-to-nine on 23 August 1692; a total eclipse of the sun took place over Mexico City. Carlos Sigüenza y Góngora (1645-1700), astronomer and mathematician, described his observation of the solar eclipse in a letter to Madrid addressed to Admiral Andrés Matías de Pez y Malzárraga (1657-1723). Sigüenza wrote that while dogs howled and street vendors shrieked at the darkening sky,¹

I stood with my quadrant and telescope gazing upon the sun, exceedingly happy...for...the privilege of beholding what only happens very rarely in one given place and about which there are so few observations in the books. The sun lay between Mercury which, about five degrees away toward the east, could be seen with the telescope since the Moon was in quadrature, and the Heart of the Lion was to the west. Farther on lay Venus, greatly cut off. The sky was everywhere covered with stars but only those of the First, Second, and Third Magnitude were visible to the south perhaps because the Moon had some apparent northern latitude.²

Sigüenza had written to Andrés de Pez, Spanish admiral of the Pensacola Bay expedition (1693), in order that his observation “might be published and read widely at the Spanish court”—the very court where his father had once been a tutor of mathematics to the young prince Baltasar Carlos de Austria.³

Sigüenza ascribed to the phenomenon of a darkened sun a significance that kept it distinct from any religious, social, or political judgment: it was the result, he said, of the moon casting a shadow as it passed between the sun and the earth. Sigüenza’s approach to astronomy was remarkable in an era when astronomers

¹ Irving Leonard, *Don Carlos de Sigüenza y Góngora. A Mexican Savant of the Seventeenth Century* (Los Angeles: UC Press, 1929), 231-32.

² *Ibid.*, 232.

³ The prince’s sudden death in 1646, at the age of seventeen, ended ties that the tutor’s family might have later enjoyed in New Spain. Possible causes of the young prince’s illness and death were discussed in: Fray Juan Martínez, *Relación de la enfermedad del Príncipe Nuestro Señor... para el Doctor Andrés de Uztárroz* (Zaragoza, 1646). The likely cause was a venereal disease or other contagious illness contracted when courtiers took the young man out carousing—an induction to adulthood.

throughout Europe still considered comets to be harbingers of calamity.⁴ Also notable was his collection of optical instruments and his sense of being part of a transoceanic network of scientists who shared and exchanged observation reports to expand the reach of their individual efforts. By 1584 all Spanish territories used the Gregorian calendar and made use of astronomical works by the influential German Jesuit mathematician Christopher Clavius (1538-1612), as well as the discussions of these works by his contemporaries. Novohispanic astronomers had a wealth of scientific books at their disposal.⁵

This chapter examines the evidence of mathematical books produced in the Americas during the seventeenth century to chart the development of astronomy in New Spain. I begin with a general overview of the reception of Copernican ideas in the Spanish Empire. Building on the work of Leonard, Trabulse, Aranda, and Ávalos and emphasising the reach of novohispanic scientists, I then trace the emerging change in conceptions of the heavens in this period through the activities of several figures, most little-known to scholars of early modern science: indigenous chronicler Chimalpahin, Mercedarian mathematician Diego Rodríguez; astronomer Sigüenza y Góngora and his debate with Jesuit missionary Eusebio Kino; and amateur astronomer Alexandro Favián in Puebla. Each scientist presents a different aspect of novohispanic astronomy: Rodríguez illustrates transoceanic ties within the European Republic of Letters as well as correspondence networks within Spanish America; Sigüenza y Góngora demonstrates the fertility of cometological debates in Mexico City; and Favián shows that in New Spain optical lenses aided hobbyist-astronomers and other experimentalists.⁶ I also examine the use of lenses for eyeglasses within the Spanish world through contemporaneous portraiture as well as Daza de Valdés' dialogue on lenses and telescopes.

⁴ For a discussion of how comets were often viewed with trepidation in the seventeenth century, see Eric Jorink, *Reading the Book of Nature in the Dutch Golden Age, 1575-1715* (Leiden: Brill, 2010), 110.

⁵ The year following Pope Gregory XIII's papal bull of 1582, Philip II issued an edict for New Spain and Peru to adjust their dates to coincide with the new calendar, which both viceroalties had enacted within two years of the royal edict. Shipping lists for departures from Seville, bibliographies of Mexico City's imprints, local monastic book inventories, and personal book collections referenced in the writings of astronomers in New Spain all document the abundance of sixteenth and seventeenth-century books relating to the mathematical sciences.

⁶ This chapter also shows the titlepages of two volumes which Athanasius Kircher's sent, from Rome, to Alexandro Favián in Mexico City. To my knowledge no scholar has identified these codices in relation to Favián and Kircher nor has the location of these artifacts been published.

Views of Astronomical Phenomena in the Spanish Empire

Beginning in the mid-sixteenth century, Copernican astronomy was taught in Spain and circulated to its overseas possessions as an alternative to Aristotle's cosmography. Aristotelian astronomy depicted an unchanging celestial realm of concentric spheres where planets revolved in circular orbits; moving objects, such as comets, existed within the Moon's sphere around the Earth, known as the "terrestrial" or sublunar realm. Copernicus reordered Aristotle's celestial bodies by placing the Sun—rather than the Earth—at the centre of the universe and reconfigured the sub- and supralunar realms. Significantly Jerónimo Muñoz, Professor of Mathematics and Astronomy at the University of Valencia (Spain), dismissed Aristotle's cosmography in his *Libro del Nuevo Cometa* (Valencia, 1573)—a work praised by Tycho Brahe.⁷ Unlike Brahe, who like many contemporaries believed that comets occupied the sublunar realm, Muñoz explicitly argued that the comet of 1572 was a moving object far more distant from Earth than the moon, thus rejecting the Aristotelian notion that the supralunar universe was fixed. By 1625 the University of Salamanca had already added Copernicus' *De Revolutionibus* to the mathematics curriculum; it remained even after the Roman Inquisition included it among the texts for expurgation in 1616. Notably, the Spanish Inquisition did not include Copernicus' text in its Index.⁸ Philip II himself owned a copy of the *De Revolutionibus* along with a considerable personal collection of astronomical instruments.⁹ Goodman's assessment of the evidence from Philip II's reign shows that within Spanish territories "there was no risk to supporters of Copernicus" because the mathematician had not made theological claims.¹⁰

Within Spain, astronomical conceptions of the cosmos departed from the traditional Aristotelian-Ptolemaic vision of the cosmos during this period, and some

⁷ *Astronomiae instauratae progymnasmata* (Uraniborg, 1602) 567.

⁸ Goodman writes that the University of Salamanca was among the earliest in Europe to add Copernicus' cosmology to the curriculum. Although the Roman Inquisition included the *De Revolutionibus* on its list of 1616 the Spanish Inquisition did not. The statutes of the University of Salamanca maintained the work. The Spanish Inquisition's primary concern was the spread of Protestantism, and as a Catholic author Copernicus was not automatically suspect. An interesting character at the University of Osuna in 1584, Diego de Zúñiga, monk and professor of theology, espoused Copernicanism when interpreting the Bible and did indeed arouse criticism for doing so. David Goodman, *Power and Penury: Government, Technology, and Science in Philip II's Spain* (Cambridge: Cambridge University Press, 1988), 53.

⁹ López Piñero, Portela Marcos, and Navarro-Brotóns, *Materiales*, 42ff; Guillermo Antolín, "La librería de Felipe II: datos para su reconstitución," *Boletín de la Real Academia de la Historia* (1927): 341. Astrolabes, armillary spheres, maps, globes, and telescopes were among the excellent instruments displayed in the king's library.

¹⁰ Goodman, *Power*, 53. The jurisdiction of the Roman Inquisition did not necessarily overlap with that of the Spanish, or Mexican Inquisitions.

of this change is reflected in the books published in Mexico City at the same time. From 1550 to 1600 the number of books printed in Mexico City on scientific matters doubled, and by 1650 they had more than quintupled.¹¹ In the first decades of the seventeenth-century an architect-engineer with a knack for Mudejar-inspired carpentry, Fray Andrés de San Miguel (1577-1644) discussed in chapter 3, designed monastic buildings for the Carmelite Order in New Spain. He also wrote about Aristotelian cosmology as an outdated model; Trabulse refers to Fray Andrés as a transitional figure because he was among the few Copernicans of his time.¹²

Scholars have identified the presence of other European astronomical works in seventeenth century book collections or cited by seventeenth century authors writing in Mexico City. Trabulse notes that the astronomical works dating to the sixteenth and seventeenth centuries outnumber by far the works produced earlier, which suggests that for this period, the trade in astronomy books around the Caribbean was thriving.¹³ From at least 1620, the works of Copernicus were popularly available through Juan Cedillo Diaz's writings. We cannot assume that all the persons who purchased and collected these works read them, and among those who did only a select few would have used them to teach others; however, the educational institutions already established in and around Mexico City by this time were the principal consumers and disseminators of recent ideas about astronomy. Just as Rome's Colegio Romano housed European scientists and Madrid's Jesuit Colegio Imperial trained mathematicians, the Jesuit Colegio Máximo de San Pedro y San Pablo in Mexico City played a key role in astronomical research during the years 1603-1767. The Colegio shaped both popular and elite conceptions of astronomical phenomena throughout the Spanish colonies. Athanasius Kircher's prodigious correspondence is one example of how Jesuit colleges throughout the world exchanged astronomical observations.¹⁴

¹¹ This estimate is based on my count of the Mexican imprints collected in the Catálogo Colectivo de Impresos Latinoamericanos (CCILA). <http://ccila.ucr.edu/>

¹² Trabulse, *Ciencia y tecnología*, 77.

¹³ *Los orígenes de la ciencia moderna en México (1630-1680)* (México: FCE, 1994), 143; "Los libros científicos en la Nueva España, 1550-1630," in *Cincuenta años de historia en México*, eds. Alicia Hernández Chávez, et al. (México: Colmex, 1993), 7-37. The scientific book collections which Trabulse used for his analysis included Melchor Pérez de Soto's famed collection (see chapter 5 below).

¹⁴ During his highly productive years as an author, the Jesuit Athanasius Kircher sent his books to the Jesuit colleges around the world. His collected letters show that these distant Jesuit institutions often responded to his books by writing him letters filled with interesting science-related news from their missionary outposts that he, in turn, might cite in his next book. For a discussion of Kircher's correspondence, see John Fletcher, "Athanasius Kircher and the Distribution of his Books,"

At the same time, the observations made by astronomers working in the Americas influenced views of astronomical phenomena in Europe. For example, the Jesuit Valentino Stansel's (1621-1705) careful observations of comets from South America received recognition in Europe during his lifetime. He was born in Moravia and taught mathematics at the University of Olomouc as well as in Prague; he maintained correspondence with these European colleagues later as a missionary in Brazil. His observations of the comet of 1664-1665 from the Bahia of All Saints were published as *Observationes Americanae Cometarum factae, conscriptae ac in Europam missae* in Ghent (1680/1682) in a portable quarto edition, and reviewed in May 1685 by the *Acta Eruditorum* (published in Leipzig), a well-known scientific journal of the late seventeenth century. His observations of what has since been named the Estancel-Gottignies Comet of 1668 were confirmed by another Jesuit missionary, Gilles-François de Gottignies (1630-1689), while stationed in India.¹⁵

According to the review, the Astrophilorum ("lover of stars") and chair of Mathematics at the Jesuit College of St. Clement in Prague, Stansel compared his observations with those made by astronomical research centres in Rome, Venice, Florence, Gdansk, Paris, Vienna, Madrid, Ingolstadt, Prague, Wroclaw, Znojmo, and Olomouc. The reviewer noted Stansel's influence: "[Athanasius] Kircher has read and cited works by Stansel."¹⁶ And near the end of his *Principia*, Isaac Newton refers to Stansel's South American observations of the comet.¹⁷

Astronomy as a pursuit of verifiable knowledge in the New World stimulated lively debates at this time to which the clash between Sigüenza y Góngora and Eusebio Kino, discussed below in detail, attests.¹⁸ But even non-professional participants took part in the larger discussions of the age as hobbyists;¹⁹ the letters

The Library 5, no. 2 (1968): 73-83; "A Brief Survey of the Unpublished Correspondence of Athanasius Kircher (1602-1680)," *Manuscripta* 13, no. 3 (1969): 150-60.

¹⁵ Carlos Camenietzki, "O cometa, o pregador e o cientista: Antônio Vieira e Valentin Stansel observam o céu da Bahia no século XVII," *Revista da Sociedade Brasileira de História da Ciência* 14 (1995): 38ff.

¹⁶ *Acta Eruditorum* 1685, 235. Translation from "Baroque Science between the Old and the New World," in *Athanasius Kircher: The Last Man who Knew Everything*, ed. Paula Findlen (New York: Routledge, 2004), 312.

¹⁷ Stansel's letters include his designs for innovative gnomonic devices, see "The Celestial Pilgrimages of Valentin Stansel (1621-1705), Jesuit Astronomer and Missionary in Brazil," in *The New Science and Jesuit Science: Seventeenth Century Perspectives*, ed. Mordechai Feingold (Boston: Kluwer Academic, 2003), 249.

¹⁸ By "verifiable knowledge" I am referring to the result of quantitative practices that could be reproduced by other persons to establish the accuracy and usability of a calculation.

¹⁹ By "non-professional participants" I mean historical agents who did not hold a post or receive payment for their scientific activities.

between Favián and Kircher illustrate the role of curious hobbyists in this process and points towards the broad, non-specialist readership of science-related publications at the time. Among them were lesser known figures such as José de Escobar Salmerón y Castro, who competed with Sigüenza y Góngora for the position of Mathematics Chair at the Universidad Real y Pontificia de México, and Martín de la Torre and Gaspar Juan Evelino, both of whom actively shaped the debates about the Great Comet of 1680, as well as Diego Rodríguez, Juan Ruiz and Gabriel López de Bonilla, whose treatises concerning comets preceded the dispute over the significance of comets. These astronomers not only wrote almanacs, but also used telescopes and participated in generating a discourse about the value and meaning of astronomy in Mexico City during the seventeenth century.

The role of missionaries in the development of astronomical knowledge deserves consideration as these missionaries included some of the best trained minds of Europe. As teachers, writers, linguists and scientists, missionaries threw themselves with gusto into the new classroom and laboratory that were the Americas.²⁰ Jesuit missionaries in particular were well known for their rigorous mathematical training and their effectiveness as educators across the Spanish territories.²¹ Forms of European science were not only researched in New Spain but taught and published there during the sixteenth and seventeenth centuries.²²

Upon the establishment of religious education in New Spain, celestial phenomena took on new connotations for the native population as well. In the Nahuatl language *Annals of Mexico* by Chimalpahin we have an early colonial indigenous perspective on how Spanish astronomers and educators changed popular views of astronomy. Chimalpahin described a solar eclipse at three in the afternoon on 10 June 1611 and drew a distinction between prior and current understandings of the event. Chimalpahin attributes the celestial event to “the covering of the face of the sun...[because] the moon placed itself before the sun and the light of the sun entirely disappeared.”²³ He explains that his current perception differs from the terms that his Nahua ancestors used to describe a solar eclipse: “as the ancients said, the sun is

²⁰ José Cervera Jiménez, "Logaritmos, astronomía y cristianismo: los religiosos como innovadores matemáticos en el siglo XVII," *Asia-Pacífico* 1, no. 1 (2015): 93ff.

²¹ The scholarship on Jesuit science is extensive; for a selection, see page 14, note 24, of this thesis.

²² Marcelo Aranda, "Instruments of Religion and Empire: Spanish Science in the Age of the Jesuits, 1628-1756" (PhD Thesis, Stanford University, 2013), 87ff.

²³ Chimalpahin Cuauhtlehuanitzin, *Annals*, 177.

eaten.”²⁴ Chimalpahin does not elaborate on what this metaphor of the sun being eaten meant within indigenous thought, but he suggests that traditional conceptualizations of the event stayed within a mythological framework rather than providing a natural explanation.²⁵ The missionary’s Aristotelian account, however, made a physical kind of sense to Chimalpahin and he describes it as a common understanding for his generation.²⁶ While his average daily entry covers one third to one half of a page, he elaborates on this topic for four and a half pages, continuing at length about this change of understanding.

Chimalpahin’s chronicle entry includes an excerpt from an account made of solar eclipses by the criollo friar Juan Bautista (1555-c.1610), who wrote in Nahuatl after training within the Franciscan order. Bautista was a theologian rather than an astronomer, and he offered his Nahua audience an Aristotelian vision of fixed celestial spheres which had long been viewed as outmoded in Valencia and Salamanca.²⁷ Rather than illustrate the latest currents in astronomy, the chronicle entry demonstrates the extent to which indigenous ideas about cosmology were changing. Franciscan missionaries, whose Order did not emphasise mathematical training, appear to have educated their indigenous converts in certain aspects of

²⁴ Ibid.

²⁵ The annual Pre-Columbian festival *Netonatiuh qualo* “The Unhappy, Eaten Sun” was an apotropeic preventative of solar eclipses; see, A. León y Gama and C.M. Bustamante, *Descripción histórica y cronológica de las dos piedras que con ocasión del nuevo empedrado que se está formando en la plaza principal de México, se hallaron en ella el año de 1790* (México: Valdés, 1832), 90. Sahagún described in his *Cosas de la Nueva España*, the helter-skelter activities that traditionally took place during a solar eclipse: shouting and making loud noises with musical instruments, rounding up and sacrificing of albinos and captives; self-puncturing with maguey needles, and using a piece of *itztli* (obsidian) as a shield to protect the wombs of pregnant women lest the rays of eclipsed light harm the developing baby. In the case of a total solar eclipse, people would shout “Never more will it shine; there are perpetual clouds, and the demons will descend to eat us.” Cited in Elías Trabulse, *Archipiélagos siderales: eclipses y astronomía en la historia de México* (Tlalpan: Secretaría de Comunicaciones, 1991), 24-25.

²⁶ For a focused case study of selective indigenous cultural change see Jean-Pierre Berthe “El Evangelio y la herramienta: el cambio técnico en un pueblo Indio de México en el siglo XVI” in *Estudios de Historia de la Nueva España de Sevilla a Manila* (México: Universidad de Guadalajara, 1994) 221-237. For a visual introduction to the technological-conceptual changes that took place during the colonial period see the collected studies in Patricia Aceves Pastrana, Carlos Viesca, and José Mainetti, eds., *Ciencia y técnica en Latinoamérica en el período virreinal* (Madrid: Grupo CESCE), 150ff. For fascinating case studies of the initial cultural changes that took place see Susan Kellogg, *Law and the transformation of Aztec culture, 1500-1700* (Norman: University of Oklahoma Press, 1995), especially 29-30, 211ff; Ruiz Medrano, *Reshaping*, 15ff. Medrano’s work is a particularly useful look at Spanish colonialism’s process of self-correction by way of the Second Audiencia and the indigenous judicial system.

²⁷ Goodman, *Power*. Biographical notes on the Franciscan theologian can be found in Nicolás Antonio, *Bibliotheca hispana nova: sive hispanorum scriptorum qui ab anno MD ad MDCLXXXIV* (Madrid: Ibarra, 1788), Vol.II; J.G. Icazbalceta, *Bibliografía mexicana del siglo XVI* (México: Andrade y Morales, 1886), 348-49.

celestial astronomy. A Nahua conception of the sun being eaten by gods and then miraculously restored was by the time of Chimalpahin's writing no longer a suitable explanation of a solar eclipse to the recently Christianized. As Chimalpahin notes, the fear inspired by a darkening of the sky would not be necessary, since "everyone [should] realize that the surface of the sun can by no means stay black, dark, dark blue for a long time, for it quickly passes."²⁸ Quoting Bautista's text in Nahuatl, Chimalpahin points out that a shadow of the moon caused the phenomenon and that the actual surface of the sun itself does not change: "When it happens that the moon places itself in front of the sun, for fully as long as they are facing each other, thereby [the moon] blocks the sun's shining and puts us in the dark."²⁹ The Franciscan's text contrasts the physical phenomenon of the eclipse with the human experience of it by describing the temporary darkness brought on by the solar eclipse as if it were the state of being under a *tetzacuillia* or a "shady shelter". This new conceptualization of a celestial event is hence domesticated for a Nahua audience through the use of a familiar vocabulary and a reference to common experiences.³⁰

Lunarios and *Prognósticos*, almanacs printed on flyleaves, were the primary means by which the greater population of New Spain encountered astronomy during the seventeenth century.³¹ The *lunarios* included celestial data and weather forecasts that were useful to farmers, sailors, astronomers, and to some doctors, as well as to readers who sought to make medical or political decisions based on their horoscope. Among others, Enrico Martínez's son Juan Ruiz (ca.1625-1685) continued his father's trade as printer-mathematician-architect and produced annual *pronósticos* between 1641 and 1676.³² To the chagrin of mathematicians like Fray Diego Rodríguez and

²⁸ Chimalpahin Cuauhtlehuanitzin, *Annals*, 179.

²⁹ *Ibid.*

³⁰ By the time of Chimalpahin's chronicle entry, two significant mathematical works had been in circulation in Mexico City among astronomers and technicians: the Sicilian Franciscan Francesco Maurolico's (1494-1575) *Arithmeticon libri duo* (1575) was reprinted in Mexico City in 1578; and what has been called the earliest printed book on ship construction was first published in Mexico City *Instrucción náutica para el buen uso y regimiento de las naos* (1578) by Diego García de Palacio. García de Palacio's work included a large section on navigational astronomy.

³¹ In addition to schooling and the serial *Lunarios*, theatre was a third source of popular ideas about astronomy in Mexico City during the seventeenth century. Juan Ruiz de Alarcón (1580-1639), a criollo lawyer and dramatist from Mexico City whose plays were published in Madrid, authored "El dueño de las estrellas." The drama portrays the doctrine of free will conflicting with popular belief in astrological predictions; see Frederick de Armas, "El sol sale a medianoche: amor y astrología en 'Las paredes oyen'," *Criticón*, no. 59 (1993): 119-26.

³² "Licencia de Juan Ruiz" AGN Universidad Vol 143 exp 66 fojas 148-149v. Also see Avalos' thesis, Appendices I and II for a sourceguide to seventeenth century *Lunario* documents at the AGN in Mexico City, as well as a list of relevant Inquisition documents.

Sigüenza y Góngora, these popular ephemeral works included astrological predictions that often made links between the suitability of specific medical practices (or political states) and the phases of the moon or arrangement of the planets. Astronomers Rodríguez and Sigüenza y Góngora defined themselves against these works, criticising them even as they participated in the production of these texts.³³

Figure 4.1: Astrologer Juan Ruiz's petition for a licence to publish his Pronóstico of 1660. AGN Instituciones Coloniales, Inquisición 12500 Volumen 670, folio 198.

³³ Ana Ávalos, "Astrology and other Occult Sciences in Seventeenth-Century New Spain," *Cronos* 9 (2006): 3ff.

Figure 4.2: Title page to Sigüenza y Góngora's Almanac of 1690, in Sigüenza's hand. AGN Instituciones Coloniales, Inquisición 12500 Volumen 670, folio 200.

Figure 4.3: “Diario y Discursos Astronómicos hechos por Gabriel López de Bonilla” AGN Instituciones Coloniales, Inquisición 12500 Volumen 670, folio 260.³⁴

Fray Diego Rodríguez and the Intellectual Networks of Mexico City

Mexico City’s culture of scientific discourse was sustained by a coterie of persons whose reliance upon quantification and empirical observation defined them as *científicos*. Fray Diego Rodríguez (1596-1668) anchored these little-known Spanish

³⁴ Bonilla’s almanac, printed in Mexico City, mentions—on this page about the visibility of an upcoming lunar eclipse—Spain and locations from across New Spain’s administrative jurisdiction. From the top of the page: Spain, California, New Mexico, Manila, Cebu, Mindanao, and Mexico City. Regions along the Pacific figure prominently in Bonilla’s almanac; this is suggestive. Astronomical data from the Philippines was readily available in Mexico City and considered a top-of-mind interest to his readers who may have been travelling to Asia or earning an income from the Manila Galleon trade. We can also glean from Mexico City authors that the world of the Pacific Ocean is as relevant as that of the Atlantic.

American communities in Mexico City and helped to establish the mathematical practices which were in full bloom later in the seventeenth century when Sigüenza trained with the Jesuit order.³⁵ Rodríguez, who later held the first chair of Mathematics and Astronomy at the Universidad Real de México, was a *criollo* friar from Atitalaquia, a suburb of Mexico City. As a member of the Mercedarian Order—what had been Charles V's and later became his grandson's preferred religious order—Rodríguez enjoyed the privileges of living in a royally-funded monastery. Philip III, remembered for little more than his piety, appears to have favoured the Order with donations which were used in the construction of opulent monastic buildings in New Spain. His viceregal appointees in Mexico City supported the foundation of Mercedarian monasteries despite initial resistance from the city council. Municipal officials as early as the late sixteenth century already argued that a proliferation of any religious orders—with their institutional reliance upon donations—would not be good for economic growth. Ultimately the expenditures were defended as investments in the spiritual wellbeing of the viceroyalty.³⁶ While Mercedarians had been founded during the thirteenth century as an ascetic mendicant order and originally aspired to undertake missionary activities in New Spain, royal favour transformed it into a locus of scientific investigation in Mexico City.³⁷

Rodríguez's scientific career began at his induction into the order in 1613. At the age of seventeen, when he was no longer devoted to the theological studies of a novice, Rodríguez had more time to spend on his chosen study of mathematics, astronomy, theoretical engineering, as well as hermetic sciences taught by the Spanish mathematician Juan Gómez.³⁸ Twenty years later, in 1637, Rodríguez was appointed the first chair of Mathematics and Astrology at the Real y Pontificia Universidad de México with a salary of one hundred silver pesos per annum. Professors of theology

³⁵ Historian Elías Trabulse first brought Diego Rodríguez's manuscripts to light in the early 1970s, and has since written the most comprehensive works on the *criollo* mathematician; see, Elías Trabulse, "Un científico mexicano del siglo XVII: Fray Diego Rodríguez y su obra," *Historia Mexicana* (1974): 36-69.

³⁶ Pedro Nolasco Pérez, *Religiosos de la Merced que pasaron a la América Española (1514-1777); con documentos del Archivo General de Indias* (Sevilla: Zarzuela, 1924), 119-24.

³⁷ Trabulse stresses that during the seventeenth century, "the Mercedarians of Mexico City focused their interests upon intellectual pursuits and [their monasteries] became an active centre of scientific studies that were neither always nor entirely orthodox." Elías Trabulse, "La ciencia en el convento: La vida cotidiana de un científico novohispano del siglo XVII," in *La ciudad barroca*, ed. Antonio Rubial García (México: Colmex, 2005), 200.

³⁸ The Spanish mathematician, Juan Gómez, was Rodríguez's superior in the Mercedarian order and quarrelled with Rodríguez as the younger man moved up the ranks. Trabulse takes this as a classic example of the power struggles between Spanish *peninsulares* and *criollos* in New Spain (ibid.)

and Aristotelian philosophy were—according to the university account books—much better paid than instructors in other fields.³⁹ Hence, teaching mathematics would have been a labour of love to Rodríguez.⁴⁰ In that same year he also assessed the city's water management project—the *desagüe*—in a statement from the university to Viceroy Lope Díez de Armendáriz, marqués de Cadereyta (in office 1635-1640) as the previous chapter noted.

Rodríguez used his east-facing monastery cell as an astronomical observatory and as a study. His writings, composed mainly of manuscripts unpublished during his lifetime, include his logarithmic tables and descriptions of how he built many of his own instruments—such as astrolabes, conic sections, and globes—based upon printed manuals or other models.⁴¹ He wrote on folio 8 of his *Discurso etheorológico* (Mexico City, 1652) that scientific knowledge was best accessed through direct observation: “When discussing matters of the physical world, nothing is as persuasive as observations made by means of the senses.”⁴² He applied mathematics to an observable and mechanical world, distinct from that of classical authorities or claims of metaphysical significance. He also built clocks. By applying his mathematical skills to the mechanics of clock-making in particular, he was preparing to make some of the most accurate observations recorded in the Americas of the early seventeenth century.

Rodríguez's calculations and observations had wide-ranging geographical and political implications. Starting at thirty-seven minutes past six on the evening of 20

³⁹ Ibid., 193-219; María Luisa Rodríguez-Sala, "Fray Diego Rodríguez: astrónomo-astrólogo-matemático, precursor de la modernidad científica nacional," in *Del estamento ocupacional a la comunidad científica: astrónomos-astrólogos e ingenieros, siglos XVII al XIX*. (México: UNAM, 2004), 85-130. Also see: Francisco de Pareja, *Crónica de la provincia de la visitación de Nuestra Señora de la Merced, Redención de Cautivos, de la Nueva España* (Mexico: Barbedillo, 1882), 250.

⁴⁰ By contrast, Sigüenza y Góngora appears—based on university records disputing his pay and tallying his absences from the lecture hall—to have enjoyed teaching less than leading viceregal cartographic expeditions. For the records of Sigüenza y Góngora's absences and requests for substitute lecturers see México Archivo General de la Nación, "Autos de la Real y Pontifical Universidad de México a cerca de diversas materias, entre los años 1560 y 1700," (Archivo de la Universidad vol. 69 tomo 1); "Multas dadas por la Real y Pontificia Universidad de México, entre los años 1679 y 1682," (Archivo de la Universidad vol. 548). Related documents can also be found transcribed in: Carlos de Sigüenza y Góngora, *Documentos inéditos de Don Carlos de Sigüenza y Góngora*, ed. Irving Leonard (México: Centro Bibliográfico Eguirara y Eguren, 1963), 24ff.

⁴¹ Examples of his logarithmic tables of trigonometric functions were later bound with his manuscript *Tractatus...de Geometría* and simply entitled “Otro quaderno” (164 fol.).

⁴² Diego Rodríguez, *Discurso etheorológico del Nuevo Cometa, visto en aqueste Hemisferio Mexicano...* (México: Viuda de Calderón 1652), folio 18. The National Library of Mexico has, since my research there in late-October 2012, made this edition available online as part of the Biblioteca Digital del Pensamiento Novohispano.
<http://www.bdpn.unam.mx/books/4c458cf485bfa3e4e0361be823002c4b/0>

December 1638, he made observations of a lunar eclipse—recorded at the end of his manuscript on how to construct clocks, *Tratado del modo de fabricar relojes*—and calculated the longitude of Mexico City.⁴³ Rodríguez's ability to make precise observations of eclipses depended upon the accuracy of his preferred tools—the clocks he built.⁴⁴ He developed his own astronomical tables, recorded in the *Doctrina general...de los eclipses*, and also mentions using those of his near-contemporaries: Christen Sørensen Longomontanus (1562-1647); Johan Philip Lansberge (1561-1632); Johannes Kepler (1571-1630), Giovanni Antonio Magini (1555-1617), and Tycho Brahe (1546-1601). Rodríguez likely found many of these tables in a work he kept in his personal book collection: Giovanni Antonio Magini's *Supplementum ephemeridum, ac tabularum secundorum mobilium* (Frankfurt, 1615).

The December 1638 lunar eclipse ended an hour and a half later at thirteen minutes past eight according to the multiple clocks he consulted. He checked his observations with that of astronomer Gabriel López de Bonilla,⁴⁵ and then applied spherical trigonometry and logarithms to calculate the geographical position of Mexico City. Three years later he refined his calculations with the observations of the solar eclipse of 9 May 1641, also recorded by his correspondent in Lima. Rodríguez was thus able to georeference Mexico City with great precision: 6 hours 45 minutes 50 seconds west of Paris.⁴⁶

⁴³ See Rodríguez's treatise on clocks, Biblioteca Nacional de México, "Diego Rodríguez. Tratado del modo de fabricar relojes (1638)," (Fondo Reservado, Manuscritos, Signatura 1521 fol. 144v).

⁴⁴ Rodríguez's geometrically designed clocks spanned the types available in the late sixteenth and early seventeenth centuries when the pendulum was not yet a standard feature for keeping time. In Spain and New Spain, clock manuals were heavily influenced by one of Philip II's most celebrated Italian engineers: Juanelo Turriano (1500-1585). As court clockmaster Turriano built an efficient hydraulic engine as well as the Smithsonian's still functional "praying automaton" using clockwork technology. A Dominican missionary from Galicia who lived for some years in New Spain, Hernando Ojea, described the clocks decorating church facades in Mexico City as copies of Turriano's—notable for their precision and beauty; see, Hernando Ojea, *La Venida de Christo y su Vida y Milagros en que se concuerdan los dos testamentos divinos, Viejo y Nuevo*, vol. 1 (Medina del Campo 1602), folio 33, Biblioteca Nacional de España, Fondo antiguo, Alcalá 6/3953.

⁴⁵ Born near Toledo, Spain and resident of Mexico City from 1628 until his death in 1668, Gabriel López Bonilla exemplified traditional scholastic astronomy in New Spain. His work offers a backdrop against which progressive astronomer-mathematicians, such as Diego Rodríguez and Sigüenza y Góngora, are often contrasted. Interestingly, Bonilla's son, also named Gabriel, later married Sigüenza y Góngora's sister, Inés, thereby linking two first-generation criollo-astronomer families. See note 113 below. See: Rosalba Tena Villeda, "Gabriel Lopez de Bonilla, un astrónomo-astrólogo en el siglo XVII mexicano," in *Del estamento ocupacional a la comunidad científica*, ed. María Luisa Rodríguez-Sala (México: UNAM, 2004), 33-84.

⁴⁶ This section is based primarily on Elías Trabulse, *La ciencia perdida: fray Diego Rodríguez, un sabio del siglo XVII* (México: FCE, 1985), 57-62. The practice of comparing simultaneous observations of a celestial event, such as an eclipse, in order to establish a location upon the globe had been in general use since the sixteenth century. The distance of Mexico City north or

Between the years 1630 and 1645, Rodríguez established a scientific academy where he hosted a *tertulia*, a meeting where intellectuals mingled with technicians to discuss recent books of astronomy and mathematics. This *tertulia* was sufficiently famous that Vicente Riva Palacio memorialized it in a nineteenth-century novel as the “Academia de Urania.”⁴⁷ During those years the gathering was sanctioned by sympathetic viceroys and other officials including the Inquisition which was, for the first fifteen years, unconcerned by its use of works by Protestant authors like Kepler and Napier.⁴⁸ Rodríguez’s *tertulia* originated in a desire to replace the Aristotelianism so frequently taught at universities of the time with empiricism. The *tertulia* participants sought to supplant reliance upon *auctoritas* with quantifiable procedures that would be checked and debated.⁴⁹ Because many of the participants identified politically with New Spain rather than with the land of their parents’ birth, over time the science-oriented gathering also came to represent a secondary cultural shift: the nascence of *criollismo*. Appointments in regional government and the upper clergy were still made almost exclusively by the Crown, leaving only those roles of local significance to the politically ambitious children of settlers. By Sigüenza y Góngora’s generation, recollections of Rodríguez’s *tertulia* had already been coloured by a more recent form of *criollo* proto-nationalism which called for greater power in the hands of those born in New Spain.⁵⁰ Nevertheless, between 1646 and 1655 key positions in

south of the Equator (latitude) was not so much in question as the distance west from a centre of astronomical data production in Europe—that is, longitude—which at various times was represented by the Madeiras, Toledo, Frankfurt, Paris, and Uraniborg.

⁴⁷ Mexican ambassador and poet Vicente Riva Palacio (1832-1896) wrote historical fiction including the rousing tale of an Irish coup-leader *Memorias de un impostor: don Guillen de Lampart, rey de México* set in Mexico City of the 1640s. In this novel inspired by Inquisition documents, the author describes an intellectual confraternity based upon Fray Diego Rodríguez’s scientific community. As in the actual *tertulia*, Riva Palacio’s “Academia de Urania” was dedicated to the study of astronomy and was associated with the Mercedarian Order.

⁴⁸ Trabulse, *Orígenes*, 64ff.

⁴⁹ Rodríguez described his departure from Aristotle by addressing the classical notion that the skies beyond the lunar orbit are immutable: “Precisely that which Aristotle removed from the skies, [their motion and change].., that is what we ought to reinstate.” See: Rodríguez, *Discurso etheorológico*, folio 13.

⁵⁰ During the mid-seventeenth century, *criollos* co-opted accounts on the Virgen of Guadalupe using a religious claim of local exceptionalism to bolster their arguments for political change. See Adriana Narváez Lora, “Guadalupe, cultura barroca e identidad criolla,” *Historia y grafía*, no. 35 (2010): 129-60.

Elías Trabulse has suggested that after 1649 the Mexican Inquisition viewed the *tertulia* as a politically subversive gathering mainly because of its *criollo* constituency; see Elías Trabulse, *Crítica y heterodoxia: ensayos de historia mexicana* (Guadalajara: Universidad de Guadalajara, 1991), 61-64. For a lucid discussion of *criollismo* consult Anna More, *Baroque Sovereignty: Carlos de Sigüenza y Gongora and the Creole Archive of Colonial Mexico* (Philadelphia: University of Pennsylvania Press, 2013), 29ff.

the Mexican Inquisition were filled by officials newly arrived from abroad whose zeal ended Rodríguez's *tertulia*.

Rodríguez's writings—currently held in the Fondo Reservado of the Biblioteca Nacional in Mexico City—include not only his work on clocks, but also a treatise on the value of theoretical geometry which students at the university in Mexico City would have used as a textbook through the late seventeenth century. This treatise identifies complex and imaginary numbers within certain Algebraic equations; although he disliked them, Rodríguez eventually admitted their necessity for defining the square root of negative numbers and solving certain polynomial equations.⁵¹ Just as he worked on fresh concepts in mathematics, Rodríguez also kept abreast of contemporary astronomy. He attributed his heliocentric model of the skies to Tycho Brahe “and many others” in the manner of those who avoided drawing the attention of censors: “The movement of the five planets Saturn, Jupiter, Mars, Venus, and Mercury—as Tycho and so many others affirm—that move around the Sun... indicate that Aristotle's model of the spheres was in error.” From the evidence of his writing on comets, Rodríguez knew Brahe's model divided the orbits differently—Venus and Mercury traveled around the Sun and then they in turn circled the Earth along with Mars, Jupiter, and Saturn.⁵² However, in Rodríguez's representation of the doctrinally unprovocative geo-heliocentric model, he does not mention the Earth.⁵³ Naming the Earth among the planets that orbit the Sun would have been an obvious departure from Brahe's acceptable model. Rodríguez relied on Copernicus' heliocentrism for understanding celestial orbits while simultaneously following the usages and currents of astronomical writing.⁵⁴

Rodríguez wrote not only serious works of astronomy but also *pronósticos* or *lunarios*. To preserve his academic reputation when writing in this genre, Rodríguez

⁵¹ Trabulse, *Ciencia perdida*, 54. René Descartes (1596-1650) famously referred to this distressing class of numbers as “imaginary” in his *La Géométrie*, (1637) because he too wished to dismiss them. Not until the circulation of Leonard Euler's (1707-1783) copious works a century later were imaginary numbers widely accepted.

⁵² Rodríguez describes the nature of celestial orbits in the language of magnetic attraction: “There exist in the skies certain forces so powerful, especially if they are near to the comet, that draw it like a magnet towards iron,” Rodríguez, *Discurso etheorológico*, folio 22.

⁵³ Tycho's geo-heliocentric model saved appearances by maintaining that the Sun orbited the Earth at the centre of the universe and demonstrated mathematically that the other planets orbited the Sun.

⁵⁴ Rodríguez most clearly indicated his reliance upon the Copernican model in his two chapter elaboration of Copernicus' figures as contrasted against those used by earlier astronomers; see Diego Rodríguez, “Doctrina general repartida por capítulos de los eclipses de sol y luna y primero de los de sol que suceden en los 90 grados de eclíptica sobre el horizonte en todas las alturas de polo así septentrionales como meridionales,” (Biblioteca Nacional de Mexico, c.1635), folios 68-74.

published his pronósticos under the pseudonym “Martín de Córdoba,” presumably because he sought to keep his popular publications distinct from his academic ones. (Later Sigüenza y Góngora wrote *lunarios* using the pseudonym “El Mexicano”).⁵⁵ But in 1647 the Inquisition decreed that all new almanacs and other astronomical forecasts—the *pronósticos y lunarios*—would need Holy Office approval prior to their publication. *Pronósticos* might contain, in addition to the phases of the moon, judicial astrology or fortune telling, and the Inquisition sought to censor judicial astrology when it conflicted with the Church doctrine of free will.

Table 4.1: Diego Rodríguez's Extant Writings, 1638-1652.

1. <i>Tractatus Proemialium Mathematices y de Geometría</i> del Fr. Diego Rodríguez Mercedario de México.	c.1635	Manuscript
2. <i>Tratado de las equaciones. Fábrica y uso de la Tabla Algebraica discursiva.</i> Por el Fr. Diego Rodríguez Mercedario de México.	c.1635	Manuscript
3. <i>De los Logaritmos y Aritmética</i> del Fr. Diego Rodríguez Mercedario de México.	c.1635	Manuscript
4. <i>Tratado del modo de fabricar relojes Horizontales, Verticales, Orient.s etc. Con declinación, inclinación o sin ella por Senos rectos, tangentes etc. para por via de Números fabricarlos con facilidad.</i> Por el Fr. Diego Rodríguez Mercedario Calzado de México.	1638	Manuscript
5. <i>Modo de calcular qualquier eclipse de Sol y luna según las tablas arriba puestas del movimiento de Sol y Luna según Tychon [Brahe].</i>	c.1640	Manuscript
6. <i>Doctrina general repartida por capítulos de los eclipses de Sol y luna y primero de los de Sol que suceden en los 90 grados de eclíptica sobre el horizonte en todas las Alturas de polo así septentrionales como meridionales.</i> Por el P. Fr. Diego Rodríguez del orden de Nuestra Señora de la Merced	c.1640	Manuscript
7. <i>Discurso etheorológico del Nuevo Cometa, visto en aqueste Hemisferio Mexicano...</i> Por el Fr. Diego Rodríguez... Cathedrático en propiedad de Matemáticas en aqueste Real Universidad de México... Con licencia en México por la Viuda de	1652	Printed

⁵⁵ See Margarita Peraza-Rugeley, *Llámenme "El Mexicano": Los almanaques y otras obras de Carlos de Sigüenza y Góngora* (New York: Peter Lang, 2013), 113.

Bernado Calderón, en la calle de San Agustín, donde se venden.

Rodríguez also wrote an early treatise on logarithms, now lost. This manuscript followed closely after Scottish mathematician John Napier's publications—*Mirifici Logarithmorum Canonis Descriptio* (1614) and the posthumous *Mirifici Logarithmorum Canonis Constructio* (1619)—and predated comparable works by renowned Spanish mathematicians José de Zaragoza and Juan de Caramuel by at least thirty years.⁵⁶ The *Trigonometría Española, resolución de los triangulos planos y esféricos, fábrica y uso de los senos y logarithmos* (Mallorca, 1672) by Zaragoza as well as Juan Caramuel's *Cursus Mathematicus* (Campania Sant Angelo, 1667), which each set out to "perfect the art of the logarithm," did not make use of Rodríguez's work as far as any extant correspondence can testify.⁵⁷ Those authors, however, did exchange letters with a successor and beneficiary of Rodríguez's: Sigüenza y Góngora.⁵⁸ Rodríguez's work on logarithms was likely the first such work in Spanish and was certainly the earliest to have been disseminated on both sides of the Atlantic.

In 1645, Rodríguez sent his *Logaritmos* to colleagues abroad with whom he corresponded. He first sent it to Europe to the Jesuit Claude François Milliet Dechaies (1621-1678), who taught applied mathematics in Marseilles and Turin. The energetic Jesuit kept up with large a network of correspondents including Rodríguez; he also wrote the *Cursus seu Mundus Mathematicus* (Lyon, 1674), built compasses, and taught hydrography, navigation, military tactics, philosophy, arts, theology, and mathematics. He did not, however, publish Rodríguez's manuscript. Scholars have not determined whether the Jesuit used ideas or techniques from the novohispanic manuscript for his own work, but it would be surprising if Milliet Dechaies chose not to make broad use of his mathematical correspondence for developing his own extensive toolkit. As there were more mathematicians in Europe than in New Spain, Rodríguez's manuscript on logarithms was probably not the Jesuit's only exposure to these new mathematical tools, but it may well have been among the earliest. It is

⁵⁶ Trabulse, "Científico mexicano," 54; 51.

⁵⁷ Petr Dvorák and Jacob Schmutz, *Juan Caramuel Lobkowitz: the Last Scholastic Polymath* (Prague: Filosofia, 2008), 218; Victoria Rosselló Botey, "L'astronomia de Juan Caramuel Lobkowitz (1606-1682)," *Cronos* 5, no. 3 (2003): 93ff; Armando Cotarelo Valledor, *El padre José de Zaragoza y la astronomía de su tiempo* (Madrid: Gráfica Universal, 1935), 150ff.

⁵⁸ Aranda, "Instruments," 56.

possible that works by Scottish Protestant John Napier were easier to access in Mexico City than they were in Lyon because of the peculiar ways in which books circulated around the Atlantic. Spanish printers and booksellers were, in times of heightened attention from the Inquisition in Spain, eager to offload any works by Protestant authors by selling the books overseas in New Spain. Trabulse has posited a black market trade in books across the Atlantic throughout the seventeenth century.⁵⁹ In New Spain, a steep price mark-up on imported books made the overseas book trade lucrative for vendors.⁶⁰

Next Rodríguez shipped his manuscript to Francisco Ruiz Lozano (1607-1677), royal cosmographer for the viceroyalty of Peru from 1665. Born in Oruro, Bolivia, Ruiz Lozano studied with and was later hired by Rodríguez to teach as a visiting professor of mathematics at the Universidad Pontifical y Real de México. After returning to Lima, Ruiz Lozano taught at the first institution of navigation in South America—La Academia Náutica de Pilotos y la Cátedra de Matemáticas, which was both a nautical academy (founded in 1657) and an infirmary for pilots located at the Hospital de Marineros del Espíritu Santo.⁶¹ Ruiz Lozano taught its curriculum in theoretical and applied mathematics for fifteen years. He also produced official measurements of the viceroyalty of Peru's Pacific coastlines, published his *Tratado de Cometas... del año 1664 y principios de 1665* (Lima, 1665), and from 1662 to 1665 oversaw mathematical instruction in Lima at the Universidad de San Marcos.⁶²

⁵⁹ Trabulse, "Libros," 7-37.

⁶⁰ There are numerous other ways for books to have crossed the ocean as well—as special orders via procurators, bound within other books, packed into trunks of voyagers' belongings or gifts, as part of sea-going libraries, or as the personal effects of naval staff who disembarked at ports. For a set of discussions of the circulation of books and other objects across the Atlantic see: Bethany Aram and Bartolome Yun Casalilla, *Global Goods and the Spanish Empire, 1492-1824: Circulation, Resistance and Diversity* (Basingstoke: Palgrave, 2014), especially 153ff; Sergio Rodríguez Lorenzo, "El Fletamento de Mercancías en la carrera de Indias (1560-1622) " *Proceso de Mercado: Revista Europa de Economía Política* VIII, no. 1 (2011): 161-208.

⁶¹ According to legend, the hospital for mariners in Peru was founded in 1573 by a Greek colonist—whose hispanized name was Juan de Acosta—for the purpose of specifically treating the illnesses that plagued sailors. By contrast in New Spain nautical training took place at major port-fortresses and focused its curriculum on artillery, the use and construction of cannons and other ships' weapons, especially from 1678 under viceroy Payo Enríquez de Rivera (1622-1684) as a response to piracy.

⁶² Luis Antonio Eguiguren, *Diccionario histórico cronológico de la Real y Pontificia Universidad de San Marcos y sus colegios; crónica é investigación* (Lima: Torres-Aguirre, 1940), 975-77, Tomo I; Jorge Ortiz Sotelo, "Los cosmógrafos mayores del Perú en el siglo XVII," *Boletín IRA*, no. 24 (2014): 135-47.

Ruiz Lozano welcomed Rodríguez's manuscript, although it appears that Rodríguez's attempt to have it published in Lima failed.⁶³ The two scientists also exchanged their observations of the eclipses of 1638 and 1641, enabling them to calculate the coordinates of major sites along the Peruvian coast.⁶⁴ Under Rodríguez's influence, Ruiz Lozano published Peru's first treatise on comets in 1654.⁶⁵ Rodríguez's mathematical rather than the fashionable Baroque-era hermeticist approach influenced astronomy in the viceroyalty of Peru for decades, and several other South American astronomers succeeded at having their observations published by European astronomers during the first quarter of the eighteenth century.

At the Academia Real de Náutica-Hospital del Espíritu Santo in Lima, Ruiz Lozano directed instruction in mathematical navigation and guided one of the Academia staff members, a Belgian-Jesuit, Juan Ramón Koenig (1625-1709), to succeed him. In 1677 Koenig succeeded Ruiz Lozano as cosmographer of Peru, left the Jesuit order c.1680, and continued as instructor of mathematics at the naval academy then at the Universidad de San Marcos in Lima (1678).⁶⁶ Koenig produced the 1638 "Carta geográfica de las provincias del Río de la Plata, Tucumán y Paraguay..." which mapped the South American continent between seventeen and forty degrees of latitude.⁶⁷ Scholars believe he produced annual astronomical reports for the viceroy, and upon his death he left a significant collection of 755 books.⁶⁸

Koenig inspired work by other astronomer-cartographers, such as Pedro de Peralta Barnuevo (Lima 1663-1743), who wrote *Prónosticos* and shared his observations of a solar eclipse. Peralta Barnuevo published lunarios and corresponded with Buenaventura Suárez, a Jesuit instrument designer in the Río de la Plata. Peralta y Barnuevo's *Pronostico* of 1719 includes the observations of the Jesuit in Paraguay

⁶³ See Trabulse, *Ciencia perdida*, 32.

⁶⁴ Ruiz Lozano dedicated his *Tratado de Cometas* (1655) to Rodríguez; see Catalá, *Ciencia y técnica*, 256.

⁶⁵ Trabulse, *Ciencia y tecnología*, 80. Peru's scientific publications were fewer in number than those of New Spain, and the works tended to keep a tight, Rodríguez-style focus on mathematics, eschewing hermeticism. Contemporaneously on the island of Cuba, Lázaro de Flores in Havana produced *Arte de navegar, navegación astronómica, teórica y práctica* (Madrid, 1673), which cites Copernicus and includes observations of lunar eclipses.

⁶⁶ The University of Lima during the viceregal period was founded by royal cédula in Valladolid May of 1551. The site was a Dominican monastery just outside the centre of the city.

⁶⁷ "Carta geográfica de las provincias del Río de la Plata, Tucumán y Paraguay, con parte de las confinantes de Chile, Perú, Santa Cruz y Brasil" Trabulse, *Ciencia y tecnología*, 80.

⁶⁸ Sotelo, "Cosmógrafos," 376, 81.

and depicts the harbours of present day Montevideo and Buenos Aires, information likely gleaned from Suárez.⁶⁹

Buenaventura Suárez (1679-1750) was a criollo astronomer on a Jesuit *reducción* in Paraguay, San Cosme, along the River Uruguay. He built instruments with the aid of Guaraní, indigenous technicians who used polished clear stone crystals for telescope lenses.⁷⁰ He also built pendulum clocks, astronomical quadrants and eventually an observatory which Suárez stocked with more tools that he acquired while traveling in Europe.⁷¹ With the aid of his students' observations, Suárez published calendars, astronomical tables, and charts of the planets in his *Lunario de un siglo...1740 a 1841*. He also maintained a fruitful correspondence with astronomers in Europe such as Nicasius Grammaticus (1684-1736) at the Jesuit Colegio Imperial in Madrid, Joseph-Nicolas Delisle (1688-1768) at Peter the Great's Academy of Sciences in St. Petersburg, and Ignaz Kögler (1680-1746) at Peking's Bureau of Astronomy. Suárez's observations were well-regarded and excerpted for reprinting in Europe; they included calculations of the distances from the Río de la Plata to Amsterdam, Berlin, Cape of Good Hope, Edinburgh, Ghent, Peking, London, Paris, Rome, Siam, Stockholm, Warsaw and the major cities of the Spanish empire. Swedish astronomer Pehr Wilhelm Wargentin (1717-1783), in his *Astronomical Tables*, cited Suárez's work.⁷² Buenaventura Suárez's influence in Europe surpassed his reputation in Spanish America.

In the Caribbean, the astronomer and doctor Lázaro de Flores Navarro (c.1625-1673) published Havana's earliest scientific book, *Arte de navegar: navegación astronómica, theórica y práctica* (Madrid, 1673), in which he cites

⁶⁹ Sixteen years later, the geodesic expedition in Peru of 1735 included Spanish military engineers Juan and Ulloa who produced *Observaciones astronómicas, y físicas ... en los reynos del Perú* (Madrid: Zúñiga, 1748).

⁷⁰ For an analysis of the optical applications and reflective properties of quartz and Peruvian anthracite see: María Luisa Calvo and Jay Enoch, "Introduction to the History of Lenses and Visual Corrections: a reference to Spain and the Spanish Colonies in the New World (XV-XVI)," *Revista Cubana de Física* 22, no. 1 (2005): 3-12, Appendix 1. On page 9 of the same article, the authors make an interesting observation about the use of glass lenses in diving helmets. Using a drawing of the "Máquina Hydroándrica" from a work by Alejandro Durand, Baron of Mazabrat in Lima, 1720, they demonstrate a wide variety of lenses in use during this period. The text accompanying Durand's drawing reads "Eye spectacles made in glass for the vision of the scuba diver." The early eighteenth-century drawing shows a diver wearing a full body diving suit with tubes coming out of the lensed helmet. At the far end of one tube are switches presumably for controlling the flow of air, and what appears to be the diver's exhalations come out of the second long tube.

⁷¹ Trabulse, *Ciencia y tecnología*, 86-88.

⁷² S. Galindo and M.A. Rodríguez-Meza, "Buenaventura Suárez (1679-1750) Part 1: Telescope maker, Jovian satellites observer," *Revista Mexicana de Física* 57, no. 2 (2011): 121-33.

Copernicus. Flores is of interest because he trained in mathematics at the Universidad de México before returning to Cuba where he wrote the *Arte de navegar*, subsequently printed in Spain. Flores' work includes instructions for building and using astronomical instruments as well as data from his calculation of Havana's longitude and his observations of the lunar eclipses dated 21 February 1663 and 6 August 1664.

Also based in Cuba, Marco Antonio de Gamboa y Riaño (1672-1728), a criollo from Havana, became a student of Sigüenza y Góngora's at the Real y Pontificia Universidad in Mexico City and succeeded Sigüenza as head of mathematics there. Gamboa y Riaño's observations of eclipses and observations of the moons of Jupiter were made using a two-foot long telescope, a pendulum clock, and a two-foot wide metal quadrant. Louis XIV's royal astronomer at the Paris Observatory, Giovanni Cassini (1625-1712), published Gamboa's calculations for the positions of Trinidad, Havana, Sancti Spiritus (Cuba), and Santa María del Puerto del Príncipe (Camagüey, Cuba) in *Memorias de la Real Academia de Ciencias de Paris* (1729).⁷³

The Republic of Letters in the early modern Americas, then, promoted an interchange of mathematical know-how and theorising with flows of new knowledge across the Atlantic and the Pacific. By contrast with European universities where Aristotelian-Ptolemaic astronomy was well entrenched, Spanish America's university-astronomers were able to make use of new approaches to astronomy in part because of their physical distance from Europe. Significant mathematical knowledge was produced in New Spain and influenced astronomers throughout Spanish America and beyond. Diego Rodríguez, at the core of these networks of intellectual exchange, influenced the next generation of mathematicians in the Caribbean, South America, Europe, and elsewhere.

Carlos de Sigüenza y Góngora and the Question of Comets

Whereas Diego Rodríguez specialized in mathematics and scientific instruments, Carlos de Sigüenza y Góngora was a polymath: an astronomer, royal cosmographer, explorer, antiquarian, and aspiring poet who lived in the mid to late seventeenth century in Mexico City. He belonged to the same generation as the

⁷³ Trabulse, *Ciencia perdida*, 168.

acclaimed baroque poet Sor Juana Inés de la Cruz. At a time when empiricism lacked its modern authority, he was a practicing mathematician who indulged in observational astronomy. The history of empirical science in New Spain could not be told without due attention to Sigüenza's writings: his monographs on comets *Manifiesto Filosófico* (1681) and *Libra Astronómica* (1691), his annual astronomical reports to the Viceroy, and his letter of 1692 to Admiral Pez, all attest to his belief in the centrality of mathematics for scientific endeavours.⁷⁴ Though Sigüenza left the Society of Jesus before taking his full vows, he furthered his scientific and clerical pursuits by gaining a competitive academic post as professor of mathematics at the Universidad Real y Pontificia de México in 1672, and by 1691 he had attained the position of *Cosmógrafo Real*—royal geographer—for the viceroy of New Spain.⁷⁵

Sigüenza's private archive of maps and documents offers us a picture of his intellectual environment and the breadth of his research interests.⁷⁶ While he is known primarily for his navigational and geographical maps, he was also an avid collector of indigenous texts, most of which later became the famous Boturini Collection.⁷⁷ He was also a lively member of the viceregal court and resided across the road from the north-east corner of the palace. Following a commission from the viceroy, he would write about a wide variety of topics including histories and weekly news reports (the

⁷⁴ Sigüenza y Góngora was influenced by Diego Rodríguez's thought and also owned many instruments including quadrants, clocks, and telescopes. He purchased one of his telescopes for 80 pesos from Jesuit Marco Antonio Capus; it had 4 lenses and was considered "the best telescope to arrive from overseas." Despite his dislike for the astrological claims often present in lunarios he published 31 lunarios between 1671 and 1700. Sigüenza's *Libra Astronómica* is "a systematic refutation of both astrology and aristotelian authority in matters of science"; Trabulse has compared section V of the *Libra* with book III, proposition XLI of Newton's *Philosophia Naturalis Principia Mathematica* and found that they independently arrived at some similar conclusions about their observations of the comet of 1681. *Ciencia y tecnología*, 86.

⁷⁵ As a novice, Sigüenza broke curfew enough times to be formally expelled. As a student of astronomy with a strong sense of his own specialness, he likely spent his evenings stargazing to the annoyance of his Jesuit superiors who expected discipline and obedience from its new members. See, Francisco Pérez Salazar, *Biografía de Carlos de Sigüenza y Góngora: seguida de varios documentos inéditos* (México: Murguía, 1928), 16.

⁷⁶ Gemelli Carreri consulted Sigüenza y Góngora's collection of Pre-Columbian manuscripts and published his own rendition of the *Tira de Peregrinación* and the Nahuatl calendar; see D.A. Brading, *First America: Spanish Monarchy, Creole Patriots and the Liberal State, 1492-1866* (Cambridge: Cambridge University Press, 1993), 363-67.

⁷⁷ These works had been bequeathed to Sigüenza y Góngora by a descendant of Texcoco royalty, Juan de Alva Ixtlilxochitl. They were confiscated from Boturini in 1743 by the viceroy of New Spain and are now at the National Museum of History and Anthropology in Mexico City. See note 88 below.

“Mercurio Volante”), as well as the case of an accidental circumnavigation by Alonso Ramírez, a carpenter from Puerto Rico, in the 1680s.⁷⁸

Sigüenza y Góngora grew up with stories of life in the Spanish court and Madrid’s intellectual circles. His father had been an early tutor to Prince Baltasar Carlos, heir to Philip IV until the prince’s early death in 1646. His mother was born in New Spain, the daughter of Spanish colonists and the niece to famed Spanish Golden Age poet-dramatist Luis de Góngora y Argote (1561-1627). On occasion Sigüenza invoked his uncle’s grandiose, baroque style to win runner-up spots in Mexico City’s public poetry contests.⁷⁹

Sigüenza’s ties abroad suggest that he was a skilled networker during his lifetime. Around 1690 Sigüenza sent a portrait of Moctezuma by Mexico City painter Antonio Rodríguez (1636-1691) to the Medici Duke of Tuscany in Florence, Cosimo III, by way of the Spanish ambassador to France, Antonio del Giudice Duke of Giovinazzo (1657–1733).⁸⁰ The painter’s skillful portrait of a proud, muscular Moctezuma wearing delicately feathered indigenous regalia made enough of an impression for it to still reside in the Museo degli Argenti at the Pitti Palace.⁸¹ As a mathematician, Sigüenza’s professional network also included Jean François Petrey, a Jesuit mathematician at the Colegio Imperial in Madrid from 1676 to 1693, and Juan Cruzado de la Cruz y Mesa,⁸² a pilot major based in Seville from 1674 to 1692.⁸³

⁷⁸ Sigüenza’s colourful redaction of a captive’s tale *Infortunios de Alonso Ramírez* (Mexico City, 1690) has been recently edited in López-Lázaro, *Misfortunes*, 99.

⁷⁹ Sor Juana was frequently a more successful participant in these poetry contests; see Leonard, *Baroque*, 172.

⁸⁰ For a catalogue of Pre-Columbian artifacts collected by the Medici in Florence see Detlef Heikamp and Ferdinand Anders, *Mexico and the Medici* (Florence: EDAM, 1972), 42. Other discussions of the gift include see More, *Baroque Sovereignty*, 256; Pérez Salazar, *Biografía de Carlos de Sigüenza y Góngora: seguida de varios documentos inéditos*, 171. The painter Antonio Rodríguez was son, nephew, and father to well-esteemed Spanish and criollo painters in Mexico City where many artists competed for viceregal and church commissions; see Donna Pierce, Rogelio Ruiz Gomar, and Clara Bargellini, *Painting a New World: Mexican Art and Life, 1521-1821* (Denver: Denver Art Museum, 2004), 71, 171ff. For a very recent study of novohispanic artwork owned by the Medici see: Lia Markey, *Imagining the Americas in Medici Florence* (University Park, Pennsylvania: Pennsylvania State University Press, 2016).

⁸¹ Perhaps one of the earliest, notable instances of artwork travelling from New Spain to the exhibition halls of Europe dates from 1520 when Albrecht Dürer noted seeing indigenous goldwork and ornaments in Brussels where Charles V had put gifts from Cortés on display. A highly talented artist himself, Dürer wrote on the 27th of August: “I saw amongst them [i.e. the objects from New Spain] wonderful works of art, and I marvelled at the subtle Ingenia of men in foreign lands.” Jan Albert Goris and Georges Marlier, eds., *Albrecht Dürer: Diary of his Journey to the Netherlands 1520-1521* (Greenwich, Connecticut: New York Graphic Society, 1971), 53-54.

⁸² A *piloto mayor* of the Casa de Contratación was a recognized navigation expert: the role consisted of examining pilots and their instruments prior to an expedition and analysing their navigation data upon return to Seville. Highly sought-after pilot majors of the Casa included figures whose institutional affiliations shifted between the powers of Europe at different points in their careers

Sigüenza met interesting characters in Mexico City: Jaime Franck, a German military-engineer who continued Adrian Boot's work on the forts of New Spain from 1686 to 1700;⁸⁴ José Azcaray (c.1670-1735), professor at the Universidad de Lima;⁸⁵ and the Flemish Jesuit later stationed in Songjian, China, Pieter Thomas van Hamme (1651-1727).⁸⁶

Sigüenza y Góngora attended the viceroy's salon-like gatherings, which included local literary figures such as Sor Juana Inés de la Cruz and others in the city's intellectual community as well as visiting scientists, missionaries, and elite travelers such as the global tourist Giovanni Francesco Gemelli Careri (1651-1725).⁸⁷ Recent arrivals of books and instruments—as well as gossip brought by travelers from Europe and Asia—were exchanged alongside international news at these gatherings.⁸⁸ Sigüenza's transoceanic network of empirically-minded correspondents enabled him to contribute his astronomical observations to those made by Jesuits in Spain.⁸⁹

One important correspondent in Sigüenza's circle was the Valencian Jesuit mathematician Bernat Josep Saragossà i Vilanova, known as José Zaragoza (1627-1679). This Jesuit mathematician, appointed in 1675 to tutor the young Charles II,

and included Amerigo Vespucci (1454-1512), Ferdinand Magellan (1480-1521), and Sebastian Cabot (1476-1557).

⁸³ Cruzado de la Cruz y Mesa's last will and testament (1711) indicates a business association with English resident of Seville, John Hooper; see "Bienes de Difuntos: Juan Cruzado de la Cruz y Mesa" AGI Contratación, 569, N.6, R.2. A pilot major's capacities included astronomical forecasts as demonstrated by Cruzado de la Cruz y Mesa's manuscript (at the Biblioteca Nacional de España) concerning a solar eclipse which he predicted would be visible from Seville in 1684: *Forma y representación del eclipse de sol que sucederá en Madrid y Sevilla el 12 de julio de 1684*.

⁸⁴ Franck appears to have earned the criollo's friendship as he is named in the 64th clause of Sigüenza's will and testament; see Aranda, "Instruments," 145-47 and 56 n. 333.

⁸⁵ Luis Antonio Eguiguren, *Catálogo histórico del claustro de la Universidad de San Marcos, 1576-1800* (Lima: Progreso, 1912), 12.

⁸⁶ On Van Hamme's missionary activities in both New Spain and China see Luis González Rodríguez, "Un cronista flamenco de la Tarahumara en 1688: Petrus Thomas van Hamme," *Estudios de historia novohispana*, no. 3 (1970): 129ff.

⁸⁷ A Spanish traveler who circumnavigated the globe twenty years earlier than Gemelli Careri, Pedro Cubero Sebastián (1645-1697), published his observations in Madrid (1680); see, Pedro Cubero Sebastián, *Peregrinación del mundo del doctor D. Pedro Cubero Sebastián misionero apostólico* (Madrid: Miraguano, 2007), 272ff.

⁸⁸ An elite traveler two decades after Carreri's visit, Lorenzo Boturini Benaducci (1702-1753) took a great interest in Sigüenza's collection and purchased much of it for his history of the Americas, *Idea de una Nueva Historia General de la América Septentrional* (Madrid, 1746). For a recent edition of the text and the comprehensive inventories of Boturini's collection see Lorenzo Boturini Benaducci, *Idea of a New General History of North America: an Account of Colonial Native Mexico*, ed. Stafford Poole (Norman: University of Oklahoma Press, 2015), 60ff; John Glass, *The Boturini Collection: Mexican Government Records and Inventories, 1742-1826* (Lincoln: Published by the author, 2004). For an examination of Boturini's ideas see, Jorge Cañizares-Esguerra, *How to Write the History of the New World: Histories, Epistemologies, and Identities in the Eighteenth-century Atlantic World* (Palo Alto: Stanford University Press, 2001).

⁸⁹ For an excellent analysis of Sigüenza and Zaragoza's professional networks see Aranda, "Instruments," esp. 145-47 and Tables 4-1, 2-3, 2-4.

was well-positioned to have shared Sigüenza's observations with mathematicians throughout Europe, including Juan Caramuel y Lobkowitz in Flanders and Italy, Giovanni Domenico Cassini at the Paris Observatory, and John Flamsteed at the Greenwich Observatory.⁹⁰ Zaragoza's own observations appeared in the *Journal des sçavans* (1677) which, like other scientific journals of its day, reviewed recent books as well as correspondence about mathematics, experiments, and instruments.⁹¹ Zaragoza names many of his correspondents in *Engaños de la otra vida manifestales para desengaño de los hombres de juyzio, que no professan las Mathematicas*, (Madrid, 1676), which shows that he had exchanged letters with Sigüenza from 1672 to 1676. Zaragoza also corresponded with Francisco Ruiz Lozano and Juan Ramon Koenig, the mathematics professors at the University of Lima.⁹²

The Great Comet, visible in Mexico City from November 1680 through February 1681, was the brightest comet of the seventeenth century, visible even during the day. Its appearance sparked public debate and scholarly discussions, and became the subject of Sigüenza's most significant work about astronomy, the *Libra Astronómica* (1690). In it he hoped to contribute his observations of Kirch's Comet (named after Gottfried Kirch, 1639-1710) to those of other astronomers. With observations from distant locations, individual astronomers then could calculate the comet's distance from the earth. Sigüenza also sought to persuade his readers to put aside their perception of comets as ill omens.⁹³ By writing in Spanish rather than in Latin, Sigüenza aligned his work with that of other practitioners of the New Science who also were writing in the vernacular.⁹⁴

⁹⁰ The Spanish astronomer and mathematician, Caramuel is the least well-known of the group; his *Cursus Mathematicus* (1670) is an original attempt to rationalize Tycho Brahe's planetary system. See Jorge Fernández-Santos Ortiz-Iribas, "Juan Caramuel's Journey from Flanders to the Palatinate: A Travel Diary Presented to Fabio Chigi in 1644," in *Juan Caramuel Lobkowitz the Last Scholastic Polymath*, eds. Petr Dvůrák, et al. (Prague: Czech Academy of Sciences, 2008), 353ff.

⁹¹ Vol. 5, Amsterdam: Pierre le Grand, 1683, p. 267

⁹² The most fascinating of Zaragoza's students and correspondents was Countess María Enríquez Porres y Guzmán, wife to the head of the Council of Castile. Zaragoza dedicated his *Esphera en común celeste y terraquea* (Madrid, 1675) to her. The countess was also known in New Spain for her study of the natural sciences and celebrated by Sor Juana Inés de la Cruz in the *criolla* poet's "*Respuesta a Sor Filotea*" (1691).

⁹³ Sigüenza states his aims: 1) to illustrate his calculations based upon observations of the Great Comet; 2) to dismiss any suggestion that anyone has yet been able to demonstrate physically or prove mathematically of what material the comet is composed; and 3) to dismiss the notion that anyone is able to base prognostications on the mere fact of the comet's appearance in the sky, see Carlos de Sigüenza y Góngora, *Libra astronómica, y philosophica* (México: Calderón, 1690), 253.

⁹⁴ Sigüenza conveys his awareness of the communicative potential of writing in the vernacular: "No ignoro las autoridades...omíto las, digo, porque no quiero latines en lo que pretendo vulgar." Ibid., 256.

His principal opponent in this polemic was Eusebius Franz Kunh, hispanized to Eusebio Francisco Kino. Baptized in Taio, in the region of Trent, in 1645 the Jesuit priest trained in Freiburg as a mathematician and was offered a professorship at the University of Ingolstadt. By 1682 Kino was a missionary settling the north-western frontiers of New Spain.⁹⁵ Before leaving Cadiz, Spain, for Mexico City, he began recording observations of the Great Comet of 1680 in his *Exposición astronómica de el cometa, que el año de 1680 por los meses de noviembre y diciembre, y este año de 1681, por los meses de enero y febrero, se ha visto en todo el mundo, y le ha observado en la ciudad de Cádiz*. Published in fluent Spanish by Francisco Rodríguez Lupercio the following year and dedicated to the Viceroy in Mexico City, this vernacular work attests to the extensive linguistic training that Jesuits received before undertaking their missionary duties.

Kino's Prologue doubles as a dedication to the viceroy of New Spain, Tomás de la Cerda, Marquis of la Laguna (1638-1692), and his wife María Luisa Manrique de Lara. The viceroy's wife was already Sigüenza's patron and Kino appears to have sought to gain her favour by dedicating his work to both the viceroy and vicereine.⁹⁶ The Aprobación, or imprimatur, was written by the very same Francisco Ximénez who introduced Alexandro Favián to Athanasius Kircher via correspondence thirty years earlier, as noted in the following section. Ximénez had by this time advanced in his clerical career and was living in Mexico City as rector of the Colegio de San Pedro y Pablo. Unlike the praise of Sigüenza's *Libra* by an unknown censor,⁹⁷ Ximénez's praise of the *Exposición* is mild, consisting mainly of a statement that Kino was well qualified to write on the topic of comets because of his expertise in mathematics and optics. Ximénez also points out the theme which Kino's prologue establishes: the comet is a sign from heaven that mortals must live justly or the wrath of God will bring the misfortunes that comets have been associated with since antiquity.

⁹⁵ Herbert Bolton, ed. *Kino's Historical Memoir of Pimería Alta: A Contemporary Account of the Beginnings of California, Sonora, and Arizona* (Cleveland: Clark Company, 1919), 28-38.

⁹⁶ Kino's adulatory words about the vicereine appear on the sixth unnumbered page of Eusebio Kino, *Exposición astronómica de el cometa* (México: Rodríguez Lupercio, 1681).

⁹⁷ The imprimatur for Sigüenza's work demonstrates a degree of enthusiasm from the Inquisition censor who wrote that the *Libra* was free of doctrinal error. The censor went so far as to make a biblical reference to the Star of Bethlehem as an example in support of Sigüenza's argument that comets were not ill-omens. What Sigüenza made of the censor's well-intentioned reference can only be imagined.

Figure 4.4: Kino's evocative titlepage invoking the favour of more than one patroness. Biblioteca Nacional de México, Fondo Reservado, RFO 082.1 GUE 131

While he dedicated his work to the viceroy, Kino's work *Exposición Astronómica de el Cometa...de 1680* (Mexico City, 1681) was motivated by the support of an influential female patron, Maria de Guadalupe of Lencastre, 6th Duchess of Aveiro (Portugal 1630 - Spain 1715), as evidenced by his correspondence

and referenced by the title page image of the Virgin of Guadalupe.⁹⁸ The Duchess of Aveiro's patronage made her home in Madrid "the information centre for the foreign apostolic work effected by missionaries from every country of Europe."⁹⁹ She held influence in Madrid, Lisbon, and Rome at more than one religious order's headquarters, and received letters written in German, Latin, French, Italian, Spanish, and Portuguese. Kino states to her in a letter that "Upper Germany has a great number of Jesuit missionaries-in-training dedicated to mathematics;" he appears to consider mathematics a tool for inspiring conversion.¹⁰⁰ Whether by tapping into the local interest in astronomical and mathematical knowledge, or by provoking curiosity—perhaps even awe—through procedural instrument use and its accompanying

⁹⁸ The work opens with a dedication to Don Tomás Antonio Manuel Lorenzo de la Cerda y Aragón Third Marquis of La Laguna de Camero Viejo, viceroy of New Spain (November 1680–June 1686). The title page, however, bears a large engraved image of the Virgin of Mexico City, often referred to as "the patroness of the Americas." The Virgin of Guadalupe became a stock image in printed books about comets in New Spain during the seventeenth and eighteenth centuries; in Diego Rodríguez's usage, Mary represented the comet itself, a benign celestial protection sent from above. (See Jorge Cañizares-Esguerra, "Spanish America: From Baroque to Modern Colonial Science," in *The Cambridge History of Science*, ed. Roy Porter (Cambridge: Cambridge University Press, 2003), 727ff.) Symbols are redolent with meanings however, and in Kino's case the image of the Virgin of Guadalupe is also an allusion to the Duchess of Aveiro's name (María de Guadalupe). The symbol of a patroness suits the Duchess, who was known during her life as the "Mother of the Missions," because she had a hand in resourcing many Christian missions around the Pacific. The text of the work itself had begun in the form of letters to the Duchess, who in her responses inquired further about Kino's observation of the comet.

The Mexico City printing house which published Kino's work, Francisco Rodríguez Lupercio and his heirs, alone produced more than 440 publications during an eighty year period averaging one publication every two months; they appear to have held different views on astronomy from the Calderon printing house. The Bernardo Calderon-Paula Benavides and heirs printing house published a notable quantity of scientific works in Mexico City during the seventeenth and first half of the eighteenth centuries; it would be interesting to examine their selection of scientific works for a printing-house specific attitude towards prognostication in astronomy.

⁹⁹ Ernest Burrus, ed. *Kino writes to the Duchess: Letters of Eusebio Francisco Kino to the Duchess of Aveiro* (Rome: Istitutum Historicum Societatis Jesu, 1965), 20. The Duchess of Aveiro funded numerous missions in the Pacific—particularly the Philippines and Marianas Islands—and others on the Pacific coasts of New Spain and Peru. Missionaries, Jesuits in particular, wrote her letters from their outposts to comment on the changes that her donations had brought while describing the geography, ethnography and climate of the mission sites. The collection of these letters gathered at her home in Madrid made it an archival centre of new knowledge about the Pacific: "For nearly half a century she assisted the missionaries and inspired them to write numerous reports and personal letters, which...constitute a vast fund of historic, geographic, ethnologic and other scientific data.... She encouraged and financed the publishing of learned works on mathematics, theology, literature, natural science, etc." See *ibid.*, 19-20.

¹⁰⁰ Herbert Bolton, *Rim of Christendom: A Biography of Eusebio Francisco Kino, Pacific Coast Pioneer* (Tucson: University of Arizona Press, 1936), 130. To explain this unintuitive pairing of interests on the part of missionaries, Aranda has insightfully pointed out that Kino's comment about his peers' training "highlights the perceived utility of mathematical knowledge in apostolic work;" Aranda, "Instruments," 105.

mathematical calculations, mathematics was a means for attracting converts to Catholicism.¹⁰¹

Sigüenza wrote the *Libra Astronomica*, his second work on comets, to respond to Kino's *Exposición Astronómica*. The *Libra* was not Sigüenza y Góngora's first foray into comet polemics. He had written a pamphlet (published on 13 January 1681) entitled "Philosophical Manifest against Comets Stripped of their Dominion over the Timid" by which he meant to free the public of their unnecessary fear that comets were harbingers of misfortune. A Flemish astrologer living at Campeche (on the Yucatan Peninsula), Don Martín de la Torre, read the pamphlet and replied with a defense entitled "Christian Manifest in favour of the Comets Maintained in their Natural Significance." Sigüenza y Góngora replied with a second pamphlet which he named "Mathematical Bellerophon against the Astrological Chimera of Don Martín de la Torre, etc." Next, Dr. Joseph de Escobar Salmerón y Castro, a physician and professor of surgery, entered the fray by publishing his own pamphlet on the comet. His assertion that the comet was made up of "the exhalations of dead bodies and human perspiration" betrayed perhaps a professional *idée fixe*—he was, after all, a surgeon who no doubt lost the occasional patient.¹⁰² This last publication earned him little more than a humorous dismissal by Sigüenza y Góngora. And finally, we have the work written by Kino.

The dispute over whether comets were ill omens began innocently. Some mutual friends of the two mathematicians warned Sigüenza that a new book was coming out that they believed would not sit well with him. He recounts in his prologue that, initially, these warnings stirred little more than his curiosity; but his mood shifted to irritation when Kino presented him with a copy of the *Exposición* and said that it would offer Sigüenza "much with which to fill [his] time." As Sigüenza recalled:

The reverend father Kino himself generously brought the *Exposición astronómica* to me one day when visiting my home as he was accustomed to do. He was taking leave of me as that very afternoon he would depart for the provinces of Sinaloa. He asked what I was working on and in response I indicated that nothing special occupied

¹⁰¹ Aranda, Seed, and Safier have posited that the "ritual" use of astronomical instruments by Europeans in the Americas impressed the natives. Patricia Seed, *Ceremonies of Possession in Europe's Conquest of the New World, 1492-1640* (Cambridge: Cambridge University Press, 1995), 100-48; Safier, *Measuring*, 5-7.

¹⁰² The doctor's pamphlet was entitled "Cometological Discourse and Account of the new Comet" (Mexico City, 1681).

my attention, to which he replied that upon reading his book, I would not be without words to write and with which to occupy my time.¹⁰³

Sigüenza took what may have been Kino's modesty, in suggesting that his *Exposición* required a rigorous mathematical corrective from a colleague, as an invitation to engage in a literary duel.

Offended by Kino's presumption about Sigüenza y Góngora's free time, he wrote the *Libra Astronómica* as an act of self-defence. The chagrin and irritation comes through very clearly.¹⁰⁴ In New Spain, popular ideas about comets at the end of the seventeenth century were decidedly in favour of Kino's rendering as indigenous astrology also associated comets with ill portents. By arguing that comets were supralunar—outside the moon's orbit—Sigüenza placed these celestial objects far from the concerns of men and women. Sigüenza's mathematics severs the supposed divine link between comets and earthly events.¹⁰⁵

Sigüenza's distaste for astrological prognostication is also clear in his *Lunario* of 1691. In 1649 an edict from the Inquisition Suprema in Madrid came into effect in New Spain,¹⁰⁶ and in seeking to promote the Church doctrine of free will, it initiated a period when the lunarios were licenced only after scrutiny by the Inquisition. To protect the "rustic and less prudent" members of the public from believing that their fates were already set, the Inquisition sought to diminish the cultural impact of fortune tellers and judicial astrologers.¹⁰⁷ Censors crossed out lines of the almanacs where

¹⁰³ Carlos de Sigüenza y Góngora, *Seis obras*, eds. Irving Leonard, et al. (Caracas: Ayacucho, 1984), 249.

¹⁰⁴ Reminding us not to think badly of Sigüenza, Leonard writes of the *Libra astronómica*: "These barbed darts are enlivening to the modern investigator for they show the great scholar to be intensely human and subject to the same temptations as the rest of mankind." Leonard, *Mexican Savant*, 68. And Anne Goldgar's work *Impolite Learning: Conduct and Community in the Republic of Letters 1680-1750* (Yale, 1995) about scholars of the Huguenot diaspora evidences a wide spectrum of only too human behaviour among its constituents.

¹⁰⁵ Interesting comparisons could be made of how religious worldviews figured in the work of seventeenth-century European astronomers and mathematicians such as Johannes Kepler (1571-1630) and Isaac Newton (1643-1727). For discussions of Newton's theological vision of the mechanical universe see, David Kubrin, "Newton and the Cyclical Cosmos: Providence and the Mechanical Philosophy," *Journal of the History of Ideas* 28, no. 3 (1967): 327, 37ff; Paula Findlen, "The Janus Faces of Science in the Seventeenth Century: Athanasius Kircher and Isaac Newton," in *Rethinking the Scientific Revolution*, ed. Margaret Osler (Cambridge: Cambridge University Press, 2000).

¹⁰⁶ AGN Ramo Inquisición tomo 670 foja 250. In the Viceroyalty of Peru, the Inquisitorial edict came into effect soon afterwards in 1650. The extant Lunarios of Lima are far fewer in number as they were produced almost exclusively by the viceregal cosmographer. "Los inquisidores Andrés Juan Gaitán y Luis de Betancurt y Figueroa al Consejo, Lima, Febrero de 1650" AHN, Inquisición, 1043, f.99r. Cited in Avalos, 291n.1195

¹⁰⁷ "[R]ustic, ignorant and the least prudent men, who believe easily and do not question what is contained in those prognostications, forget that the predictions contained within the *lunarios*

these works diverged from purely astronomical and meteorological forecasts and ventured into prognostication. In order to receive the necessary ecclesiastical licence for publication, the author frequently made the necessary excisions and proceeded to print their *lunarios* soon afterwards so that they appeared at the appropriate time of the year. These ephemeral publications sold well and were at times a steadier source of revenue for their authors than their university income.¹⁰⁸

The mandate to keep the texts of *lunarios* to the predefined topic of weather, phases of the moon, eclipses, and comets was, depending on the attentiveness of the censors, at times strictly enforced.¹⁰⁹ When in 1691 Sigüenza y Góngora included within his *lunario* a suggestion that astrology and prognostication were unfounded and not credible, censor Agustín de Dorantes required him to excise the digressive statements before publication.¹¹⁰ Sigüenza's retort that he saw nothing wrong with the comments was ignored, and in the end he eliminated the offending sentences in order to be published.¹¹¹ In this instance the Inquisition censor appears to have sought a normative consistency for the genre of the *lunario* texts; the *lunarios* were not the appropriate venue for irony or argument about legitimate knowledge,¹¹² since they were regarded by the Inquisition to function as purely descriptive rather than argumentative works. Nevertheless the censors' proscriptions did promote something akin to a strictly "scientific" approach to the *lunario* texts in so far as they prevented astrologer-astronomers from writing predictions about human affairs.¹¹³ Sigüenza y

depend upon human volition and free will. To remedy this, the Inquisitor General and Bishop of Placencia request that when you receive this missive, you notify those who are in the process of composing or printing *lunarios* as well as the printing houses of Mexico City (and those within the jurisdiction of the Mexican Inquisition), so that from now on only prognostications with relevance for navigation, agriculture, and medicine as they are related to natural causes [such as the weather] may be written and printed. Madrid, 26 October 1647." Ana Ávalos, "As Above, So Below: Astrology and the Inquisition in Seventeenth-Century New Spain" (PhD Thesis, European University Institute, 2007), 291.

¹⁰⁸ University account books indicate that during particular years, members of the teaching staff filed complaints that their salaries had not been fully paid. See: Cristóbal Bernardo de la Plaza y Jaen, *Crónica de la real y pontificia Universidad de México, escrita en el siglo XVII*, ed. Nicolás Rangel (México: Museo Nacional de Arqueología, Historia y Etnografía, 1927), 393-94.

¹⁰⁹ Trabulse wittily points out that the Inquisition promoted a "modern" sensibility of scientific knowledge: "It is interesting and odd to see theologian-censors defending scientific rationality against astrologers..." Trabulse, *Orígenes*, 120.

¹¹⁰ Ávalos, "Astrology," 295.

¹¹¹ Not all Inquisition censors would have necessarily asked Sigüenza to tame his remarks about the foolishness of astrology; Antonio Núñez de Miranda was an Inquisition censor whose editorial comments on the *Lunarios* of the 1670s indicate a bias against astrological speculations in the almanacs; see Trabulse, *Orígenes*, 127-31.

¹¹² Ávalos, "Astrology," 99.

¹¹³ Twenty-six years earlier a similar conflict between an Inquisition censor, Ortíz de los Heros, and the astronomer López de Bonilla took place. This time however, Bonilla argued for his right

Góngora seems to have chafed at his censor's disregard for mathematically-skilled astronomer-priests.¹¹⁴

Sigüenza ends the *Libra* by requesting other astronomers to contact him to compare observations and develop a better description of the Great Comet's trajectory. Such a request demonstrates his approach to the cumulative nature of scientific endeavours:

If some mathematician... wishes to communicate with me observations on eclipses, either his own or those of someone else, and especially of the Moon from 1670 on, I shall send him mine from the same date with the utmost liberality.¹¹⁵

Sigüenza's book appears to have circulated within the Spanish empire; moreover, his materialist approach to cometological phenomena put him within a productive network of mathematicians in the Viceroyalty of Peru and in Spain.¹¹⁶

At least six comets were visible from Europe and the Americas during the seventeenth century—it is no wonder that comets were the topic of many discussions in print on both sides of the Atlantic. Sigüenza's desire to participate in a larger forum of astronomical observation, including works such as Pierre Bayle's *Various Thoughts on the Occasion of the Comet* (1682) and Newton's *Principia* (1687), demonstrates his awareness that he was a member of a larger community of knowledge production. He hoped his *Libra Astronómica* would circulate within the Jesuit network of information exchange.¹¹⁷ Although his overseas correspondents likely included mathematicians known to his father in Madrid, Sigüenza did not

to publish astrological predictions in his *Diario y Discursos Morales y Políticos según... Eclipses del Año de 1665* without the intrusion of censors. Trabulse notes that Bonilla wrote an Advertencia "that was exemplary for its lack of tact and diplomacy" to the censors who would read his work and be required to issue a licence for its publication. Despite his debate with the Inquisition, Bonilla made at least some of the changes and obtained his licence to publish within two weeks of the initial application for a licence: see Trabulse, *Orígenes*, 120-26. López de Bonilla's son later married Sigüenza y Góngora's sister (see note 45 above). The two families must have had animated gatherings as they clearly shared an interest in astronomy although a different sense of what it was good for, a talent for disputation, and a healthy disregard for censorial opinions.

¹¹⁴ Autos AGN Instituciones Coloniales, Inquisición 12500 Vol. 670

¹¹⁵ Leonard, *Mexican Savant*, 56. Leonard's translation.

¹¹⁶ Sigüenza wrote in his Introduction to the *Libra* that he was happy to be corrected by other astronomers when mistaken, see Sigüenza y Góngora, *Seis obras*, 248. His sense of being a small part of a collective scientific enterprise is notable. For a discussion of the historically contingent function that was a collective vision among scientists of the early modern period, see Lorraine Daston and Peter Galison, *Objectivity* (New York: Zone Books, 2007), 35ff.

¹¹⁷ Sigüenza's *Libra* was transported to Manila during the final decade of the seventeenth century; see Angel Aparicio and Estrella Majuelo, eds., *Catalogue of Rare books: University of Santo Tomas Library*, vol. 2, part 1 (Manila: University of Santo Tomas, 2006).

succeed in having his works published abroad as did his peers located in various isolated sites in South America a generation later.¹¹⁸

Kino never replied to Sigüenza y Góngora—after all, the *Libra* was not published until ten years after the minor offence took place. Very likely Kino had little time for intellectual sparring. He was a missionary, and only passed through Mexico City en route to converting indigenous peoples in the Sonora desert. Or perhaps Sigüenza y Góngora's arguments went unacknowledged precisely because in his momentary distress over being situated outside the Habsburg Court from which Kino had just arrived, he had broken with his own sense of the customs of civil disagreement. Sigüenza y Góngora likely delayed the publication of his work from a reluctance to upset Kino in return, and by the time it was printed, in 1691, the excitement over the comet of 1680/81 had passed.

The *Libra Astronómica* recounts the appearance of the greatest comet of the seventeenth century and alongside the work that inspired it, Kino's *Exposición Astronómica* (1682), leaves a record of the major contending views on the scientific endeavours undertaken in New Spain. The debate between Sigüenza y Góngora and Kino about comets is one of the earliest disputes of a scientific matter in the Americas that we know took place in print.¹¹⁹ Within the forum of printed texts, we have an early polemic over a matter of scientific ontology involving multiple members of the reading public and publishing fraternity in New Spain. In it we glimpse how the printed treatise changed roles between high and low registers of scientific authoritativeness.¹²⁰ Empirical science and the printed book developed during the early modern period in a parallel struggle to establish themselves as purveyors of

¹¹⁸ A possible explanation for the success of his Jesuit peers was the sheer number of Jesuits on the South American continent, particularly among the Paraguayan *reducciones* by the start of the eighteenth century. The Jesuit presence and global network were very strong from the last quarter of the seventeenth through the middle of the eighteenth century as Aranda has demonstrated. The fact that these well networked astronomers could offer celestial observations from previously unknown locales across the South American continent also contributed to their success in finding publishers abroad. Sigüenza y Góngora had neither the novelty of his location to offer nor the tight links within the Society of Jesus to rely upon when seeking publishers; nevertheless, he managed to find receptive interlocutors in Madrid, Lima, and Manila. Sigüenza's *Libra Astronómica* appeared in Spanish and Philippine Island libraries before the eighteenth-century.

¹¹⁹ For more on the debate see: Leonard, *Mexican Savant*, 55ff; Anna More, "Cosmopolitanism and Scientific Reason in New Spain: Carlos de Sigüenza y Góngora and the Dispute over the 1680 Comet," in *Science in the Spanish and Portuguese Empires, 1500-1800*, eds. Daniela Bleichmar, et al. (Palo Alto: Stanford University Press, 2009), 115.

¹²⁰ The relationship of the printed book to the legitimation of science is addressed in Adrian Johns, *The Nature of the Book: Print and Knowledge in the Making* (Chicago: University of Chicago, 1998), 58ff.

knowledge that could be trusted or taken seriously by readers who might disagree and also dispute a matter in print. Whereas Sigüenza publicly disdained Kino's *Exposición Astronómica*, the poet Sor Juana Inés de la Cruz (1651-1695) praised the book in a sonnet. Each of these figures sought to establish or maintain the patronage of the viceroy or vicereine; clearly, intellectuals fascinated by scientific matters in Mexico City extended their social circles outwards from the viceregal court.¹²¹ By reviewing Kino's book, Sigüenza illustrates how public debate in Mexico City could develop entirely within the realm of the critical reception of texts.¹²²

Alexandro Favián and the Mexico City-Puebla Optical Instrument Network

In 1583, Philip II's project to identify the longitude of Manila and Mexico City had required astronomers to observe lunar eclipses simultaneously from different sites. But from the late seventeenth through mid-eighteenth centuries, new practices such as observing the phases of Jupiter's moons by way of a telescope offered a more practical alternative. As early as the mid-seventeenth century, Novohispanic scientists used telescopes to make astronomical observations. Fray Diego Rodríguez wrote of his instrument construction as did the amateur Alexandro Favián.¹²³

Optical instruments require glass. Evidence of glass production in New Spain dates to the second half of the sixteenth century, and the glass used in optics (as opposed to building materials, decoration, or domestic use) required specialized grinding or polishing machines.¹²⁴ Glass production on the Iberian Peninsula dates back to Roman practices of Late Antiquity, and it is well known that the first Viceroy of New Spain, Antonio de Mendoza, travelled from Seville to Mexico City in 1535 accompanied by glass blowers. His plan to establish a glassworks in Puebla, a key

¹²¹ Sor Juana's Sonnet 205 "Applauding the Astronomical Science of Padre Eusebio Francisco Kino" does not appear among the preliminaries of the *Exposición* presumably because she composed the poem after his book went to print.

¹²² The debate between Sigüenza and Kino also demonstrates how mathematics and scientific instruments were employed in New Spain both within the context of religious orthodoxy and for promoting the conversion of neophytes.

¹²³ Trabulse, *Ciencia perdida*, 63.

¹²⁴ The Archivo General de la Nación in Mexico City includes production records for the glassworks in Puebla de los Angeles for the late sixteenth century. During the period of the viceroys, decorative glass and high-end domestic glasswares in New Spain were largely imported from Spain, Venice, and Bavaria as evidenced by artefacts currently held in the Museo Nacional del Virreinato (Tepozotlán, Mexico).

suburb of the capital,¹²⁵ had come to fruition by 1542. In that year he reported to the Holy Roman Emperor Charles V (King Charles I of Spain) that “three kinds of glass are worked: crystal-white, blue, and green which supply Spaniards and natives of these regions as far as Guatemala and beyond, and [particular] types of glass even to Peru and other countries.”¹²⁶ This glassworks appears to have been the source of much of the glass produced in the Americas during the early decades of colonization. Scholars have not ascertained what portion of this glass went to the production of optical instruments and lenses. Specialized grinding and polishing tools for lensmaking were likely made by individual scientists on a small scale.¹²⁷ An inventory of books received by Mexico City booksellers lists among its five cases at least one work specifically about glass lensmaking: Francisco Furti’s *Libro para labrar vidrios de anteojos* (1618).¹²⁸ The network of scientific instruments and glass curios existed between Mexico City and the glassworks at Puebla, but also included Seville and Rome as the correspondence between Athanasius Kircher and Alexandro Favián illustrates.¹²⁹

Alexandro Favián (c.1624-1682) was a *criollo* clergyman who attended Jesuit schools, and was one of many who attempted to build optical instruments for

¹²⁵ Medrano explains the Second Audiencia’s founding ideals for Puebla in Ruiz Medrano, *Reshaping*, 40-41. For an insightful study of early family-group migrations to Puebla see Altman, *Transatlantic Ties*, 9ff.

¹²⁶ Manuel Romero de Terreros, *Las artes industriales en la Nueva España* (México: Robredo, 1923), 175-76.

¹²⁷ Elías Trabulse posits that Sigüenza y Góngora built his own telescopes. This would have been possible assuming that the requisite lenses were either imported or produced at least in part at the Puebla glassworks. Specialty lenses of unknown provenance were sold in Mexico City by the last quarter of the seventeenth century: a 1689 census of businesses lists at least one shop in the capital dedicated entirely to selling eyeglasses. The archival document is cited in Francisco de la Maza, *La ciudad de México en el siglo XVII*, vol. 95 (México: FCE, 1985), 218. In seventeenth century Europe, lens polishing and grinding machines were often trade secrets and made by astronomers; see Silvio Bedini, “Lens Making for Scientific Instrumentation in the Seventeenth Century,” *Applied optics* 5, no. 5 (1966): 687ff.

¹²⁸ AGN Ramo Inquisición Tomo 581: Documento Num. XIV “Memoria de los Libros que llegaron de España a Juan de Oviedo y Cordova” Edmundo O’Gorman, *Boletín del Archivo General de la Nación* Tomo X, no. 4 (1939): 806; number 406.

¹²⁹ Francisco Ximénez introduced Favián to Kircher via correspondence but by 1667 Favián’s enthusiastic letters to Kircher soon eclipsed the epistolary friendship that Ximénez had with Kircher. A helpful Genoese importer—and acquaintance of Favián’s father—Francisco María Tassara served as a shipping intermediary, and transported the gifts and crates that Favián exchanged with Kircher. Tassara wrote nine letters to Kircher to advise him on the status of the gift shipments. Interestingly, Tassara notes in his first letter to Kircher that Alexandro Favián reminded Tassara of Favián’s father—both men were “*científicos*” and “interested in curious machines”; Francisco María Tassara, “Letter from Francisco María Tassara in Genoa to Athanasius Kircher in Rome, 18 January 1664 (Archivio Pontificia Università Gregoriana Vol. 562, Epistolario Kircher VIII, fols. 130r-130v.),” in *La Luz Imaginaria: Epistolario de Atanasio Kircher con los novohispanos*, ed. Ignacio Osorio-Romero (México: UNAM, 1993), 41-43.

astronomical purposes. Favián engaged in a lively twenty-year correspondence with a Jesuit polymath in Rome, Athanasius Kircher (1602-1680).¹³⁰ While quite the mechanical tinkerer and a fan of repairing clocks, Favián, unlike Sigüenza, never held professional posts in a scientific field. Favián was an enthusiastic student of Athanasius Kircher's many curious, encyclopedic volumes and praised the author's works so highly in his letters that he charmed the author. Over the years they engaged in gift exchanges. Favián sent quantities of cacao with cinnamon and sugar, dried chili peppers, an elaborate feather artwork portrait of Saint Athanasius made by local indigenous artisans, and a few bars of silver to which Kircher responded with supplies of his new books and parts for the scientific instruments that Favián requested, namely a helioscope, a telescope, and a new kind of spring-driven clock.

¹³⁰ The correspondence was transcribed in Rome by Ignacio Osorio-Romero (1941-1991). Osorio-Romero was a distinguished Mexican intellectual historian whose publications include a study of seventeenth-century neo-latin scholarship in New Spain, a history of colonial Jesuit university professors, and a history of novohispanic libraries. His collection of transcribed letters in *La Luz Imaginaria* (1993) was published posthumously and, other than a brief biographical introduction, lack the historian's analyses.

Figure 4.5: Last page of Favián's letter to Kircher, 2 February 1661, Tomo IV 141r. Archivio Pontificia Università Gregoriana (Rome).¹³¹

Figure 4.6: Vol.1 of Kircher's *Musurgia Universalis* gifted by the author to Alexandro Favián. Biblioteca Palafoxiana, Puebla (Mexico), PAFX NX 290 K5 t.1.¹³²

¹³¹ "Favián's letter to Athanasius Kircher, 2 February 1661." Photo provided by the Stanford Digital Kircher Correspondence Project which is maintained by Stanford University Libraries.

¹³² Note the dedication at the foot of the page. The surprising addition of handcoloured decorations on the title pages as well as other pages within the volumes appear to have been Favian's; they echo the spirited appreciation for Kircher's works that Favian expressed in his correspondence.

Figure 4.7: Vol.II of the *Musurgia Universalis* by Kircher gifted to Alexandro Favián PAFX Q173 K5 t.2.¹³³

Favián's desire to better understand Kircher's ideas and machines manifests itself in an experimentalist approach to optics. In his second letter, Favián's requests reference the latter's book *Ars Magna Lucis et Umbrae* (Rome, 1646) and display his intent to test the mirror projects described in the book: "And so, in order to work with this marvel [the *Ars magna*], if you would be so generous as to send me the necessary mirrors, one made of metal and the other of crystal in the shape of a hyperbola."¹³⁴ Later on in the same letter, Favián describes his attempts at recreating an experiment described in Kircher's *Ars magna* (1641). Using glass that Favián had made

¹³³ In February 2013, I consulted fifteen volumes of Athanasius Kircher's works at the Biblioteca Palafoxiana and only one was not a first or second edition. The codices show library markings, *marcas de fuego*, from a variety of early colonial convents which suggests that, during his lifetime, Kircher was effective at distributing his books in New Spain and making them popular—he was an exemplary marketer of his own books.

¹³⁴ Ignacio Osorio Romero, *La Luz Imaginaria: Epistolario de Atanasio Kircher con los novohispanos* (México: UNAM, 1993), 27 "Alexandro Favián a Atanasio Kircher (Puebla, 9 de mayo de 1663)" transcribed by Osorio Romero from the APUG Vol. 565 (Epistolario Kircher XI), fols. 137r-145v. Osorio, *Epistolario*, 20-39, 27. The Kircher Correspondence Project includes this letter among those digitized by Stanford University, <http://web.stanford.edu/group/kircher/cgi-bin/site/>

especially and which he thought could not have been better fashioned, the experiment nevertheless failed because he needed more information. He inserted a magnet between two halves of a small hollow glass sphere suspended within a slightly larger glass sphere, also cut in half, but the project could not work without knowing what liquid was dense enough to create the suspension: “And so I ask that Your Reverence may do me the kindness of writing me with an explanation of this [problem in the experiment], so that I may not be left without knowing how to work something of such delight and wonder as your remarkable machine of the spheres.”¹³⁵ As an active reader of Kircher’s books, Favián tested the experiments regardless of whether they were written as thought experiments or genuinely reproducible observations. Favián treated the books as if they had been written for experimentalist-hobbyists like himself.¹³⁶

Though professionals like Sigüenza y Góngora likely used optical apparatuses most frequently,¹³⁷ the instruments were also employed by “amateur” scientists like Favián to make astronomical observations and experimental machines.¹³⁸ Lesser-known figures such as Favián’s Genoese cargo handler, Francisco María Tassara, facilitated the movement of optical-instrument parts between Europe and Puebla. The trade in glass was already well-established between Puebla and Mexico City, and outwards from Mexico City to Acapulco linking New Spain to Asia and Peru.

Lenses were crafted in the seventeenth century not only to engage in empirical observation or aid nautical travel, but also to improve ailing sight. Based on paintings from the period, spectacles were popular in Spanish society during the sixteenth and seventeenth centuries, a fashion that continued in New Spain.¹³⁹ A sampling of late sixteenth through mid-seventeenth century portraits shows Spanish bishops, poets and viceroys wearing spectacles (see Fig.4.8 - 4.12). That middle-aged professionals who

¹³⁵ Ibid., 29.

¹³⁶ For Kircher’s perspective on this correspondence see Paula Findlen, “A Jesuit’s Books in the New World, Athanasius Kircher and the His American Readers,” in *Athanasius Kircher: The Last Man Who Knew Everything* (New York: Routledge, 2004), 329-64.

¹³⁷ Sigüenza y Góngora also used microscopes. He described in his letter to Admiral Pez how by using a microscope he was able to identify the cause of the corn blight in 1692: “I...could only see black and exceedingly small specks on the stalks and spikes of a cluster like fly-specks until I discovered, by making use of a microscope, a swarm of tiny dark-brown creatures not larger than the tip of a needle. That it may seem tiny I will say that its form and feet resembled that of a flea while it had covered wings like that of weevils (gorgojos). Either by means of its wings or its feet it jumped about with strange agility.” Transcribed and translated in Leonard, *Mexican Savant*, 233.

¹³⁸ Favián discusses the magnification qualities of different types of optical instruments including telescopes in his second (February 1661) and fourth (January 1666) letters to Kircher.

¹³⁹ José Roberto Peralta-Rodríguez, “Desarrollo de la optica oftálmica y uso de anteojos en la ciudad de Mexico durante los siglos XVI-XVIII,” *Secuencia* 62, no. Mayo-Agosto (2004): 8ff.

handled texts on a daily basis would take advantage of lens technology is unsurprising, but that they found it modish to wear the glasses in their portraits is. Eyeglasses became emblematic, indicating the wearer's attainments and intellectual tastes.

Figure 4.8: Cardinal Fernando Niño de Guevara (1541–1609).

Figure 4.9: Luis de Velasco, Viceroy of New Spain (c. 1534-1617).

Figure 4.10: Poet Francisco de Quevedo (1580-1645).

Figure 4.11: Diego Carrillo de Mendoza y Pimentel, Viceroy of New Spain (1570- 1631).

Figure 4.12: Astronomer-Poet Carlos de Sigüenza y Góngora (1645-1700).

A fashion for eyeglasses made it a worthy subject for a work to which modern ophthalmology attributes its origins. Benito Daza de Valdés' (1591-1634) *Use of Eyeglasses for all Types of Vision, wherein it is explained how to assess one's vision needs... and the preservation of one's sight is discussed* (Seville, 1623) is among the earliest European treatises entirely dedicated to optometry.¹⁴⁰ While Books I and II are expository descriptions as well as figural representations of eyes and eyeglasses respectively, Book III explains how glass lenses are made, deployed, and bring distant (or near) figures into focus, and Book IV concerns telescopes.

Valdés employs a popular pedagogical approach—teaching through the example of pleasing or amusing dialogues (*docere et delectare* or *enseñar deleitando*)—cited by seventeenth-century Spanish authors.¹⁴¹ As the figure of the Optometrist states in response to a question about the pipe organ-like range of sizes before them: “The various lengths enable you to see at different distances. The longer the telescope, the farther away you can see with it—provided it is well made. But a shorter one lets you see farther than a longer one, if the shorter one has better optics. If both are of equal quality, the longer one enables you to see farther.”¹⁴² The dialogue has introduced the pros and cons of long versus short focal lengths: when the lens quality is equal, the long focal length is preferable while the shorter telescopes are more portable. The final dialogue, entitled “Using Telescopes to See at a Distance,” gives us an idea of the extent to which astronomers and hobbyists used telescopes in the Spanish world:

Leonardo: Maestro, which size telescope do you consider best?

Optometrist: The telescope of one vara, it seems to me, is handy for seeing just about anything. Last night I trained all these telescopes on the moon. *Though the longer ones would reveal the craters and the rugged terrain, with this one of one vara, I could see almost the same detail and more comfortably.* However, because the object of this

¹⁴⁰ Benito Daza de Valdés, *The Use of Eyeglasses*, trans. Paul Runge (Oostende: J.P. Wayenborgh, 2004), 2.

¹⁴¹ Spanish Golden Age authors, including the dramatist and poet Félix Lope de Vega y Carpio (1562-1635) and novelist Miguel de Cervantes Saavedra (1547-1616), cited the maxim that instruction is best delivered by way of pleasing discourse. Daza de Valdés was employed as an Inquisition notary and his book is written as an illustrated reference manual; nevertheless, the author sought to sweeten the reader's task with amusing dialogues and the various applications of optical know-how. The most agreeable sections of the dialogue deal with *camera obscura* experiments wherein a single lens, a tiny opening of light, and a very dark room are used to project an image of the outdoors upon a sheet of paper or the enlarged shadow of an insect upon a far wall. *Ibid.*, 176. Such intriguing techniques were used by painters and early entomologists in order to enlarge and project the object of their attention and then trace its image.

¹⁴² *Ibid.*, 172.

instrument is to see as far as possible, the long ones are worth the trouble and not inconvenient provided you know how to use them.¹⁴³

The optometrist notes that his shortest handheld telescopes were very convenient for “finding people in the plaza” but he recommends the optimized ones that offer the longest possible range for the greatest ease of use. His preferred telescope size is one *vara* (between 2 1/2 and 3 feet) long for its manageable length and its good visual detail. He also notes that the longest telescopes provided him even more detailed views of the moon’s rugged surface but that his favourite would do if only one had to be chosen.

The charm of the text lies in the relaxed, informal manner in which the dialogue unfolds; speakers ask one another questions and share either what they have experienced themselves or have heard from friends who are not present. The optometrist, playing the part of an authority in optics, provides the others with his technical understanding of lenses by discussing their degree of curvature. He also dispels rumours about the magnifying abilities of telescopes:

Leonardo: Someone who considered himself well informed said that he had a telescope that enlarged objects eighty times and made each star look as big as the moon.... What do you think of this?

To which the optometrist replies:

Based solely on what I have seen and the experiments I have performed with telescopes, *this two-lensed instrument cannot show the stars large*, no matter how big the telescope or how many degrees the concave lens that is applied to the eye has. Only when looking at *the moon, which is much closer than the nearest star*, and at things here on earth, can you appreciate how much the telescopes enlarge.¹⁴⁴

The optometrist notes that the telescopes which he has used are capable of making the stars “more vivid and sparkling” but are not capable of enlarging stars the way they can the moon and planets.¹⁴⁵ These comments illustrate three key understandings about astronomy and optics that held currency within the early modern Spanish empire: 1) the moon’s surface is uneven; 2) the stars are “immensely distant”;¹⁴⁶ 3) the utility of a telescope lies in the workmanship and quality of glass

¹⁴³ Ibid., 173. Emphases mine.

¹⁴⁴ Ibid., 174. Emphases mine.

¹⁴⁵ Ibid., 173.

¹⁴⁶ Ibid.

lenses as well as the degrees of lens curvature.¹⁴⁷ Daza de Valdes' work suggests that just over a decade after Galileo Galilei first described the moon's uneven surface in his *Sidereus Nuncius* (Venice, 1610), Galilean telescopes had proliferated, and that the moon was no longer thought to be an idealized sphere in an Aristotelian cosmos.¹⁴⁸

From optometry to astronomy, glass lenses mattered most. The Galilean telescopes described in Daza de Valdes' book on optometry had lenses which required a grinding mechanism to shape the glass and minimize chromatic aberration around the edges; presumably these small grinding machines were available or producible in Spain and New Spain. The glass itself needed to be of a good quality and free of air bubbles.¹⁴⁹

Conclusion

During the early modern period, "scientific instruments" included not only the materials of observation but also the materials of recording and disseminating those observations. Letters and manuscript accounts, descriptions of natural history and astronomical observations provided the usual means for communicating and exchanging information about the natural world during the early modern period in Europe. Similarly in New Spain the manuscript was the scientists' first choice for sharing data among colleagues. Nevertheless, the print medium in New Spain was significant from the earliest days of colonization and became a forum for the publication of diverse scientific writing. Works belonging to a scientific genre, broadly defined, increased noticeably after 1600 in Mexico City and Puebla.

During the sixteenth and seventeenth centuries in New Spain, European telescopes were used both by professional astronomers and hobbyists. Astronomers who used telescopes included *criollos* such as Sigüenza y Góngora in addition to foreign-born missionaries, navigators, and travelers passing through the viceregal capital. From indigenous sources, we know that Chimalpahin was able to observe the solar eclipse of 1608 without the use of special tools. Even so, scientific instruments

¹⁴⁷ Ibid., 175. The Optometrist explains what is needed in order to build a telescope: "The size of the telescope is determined by the distance in degrees its convex lens requires... I would say that the ideal ratio between the concave and convex lenses for telescopes should be as follows: A convex lens does best with a concave lens of three degrees and must have a telescope length of four *varas*. A convex lens of half degree goes with six degrees of concavity..." Ibid.

¹⁴⁸ See J.A. Ruffner, "The Curved and the Straight: Cometary Theory from Kepler to Hevelius," *Journal for the History of Astronomy* 2 (1971): 178ff.

¹⁴⁹ Bedini, "Lens Making," 687.

were used at the Jesuit College, San Pedro y San Pablo, in Mexico City from the early days of its first Chair of Mathematics and Astronomy, Fray Diego Rodríguez. One hundred and eighteen works of astronomy published locally between 1550 and 1700 offer evidence of these instruments being used by trained hands and show that the sale and, likely, the production of lenses was of significant concern to novohispanic intellectuals.

Chapter 4 has examined the influence of novohispanic scientists upon astronomers and cartographers elsewhere in the Spanish America and within European networks of scientific correspondence. The historical figures in this chapter illustrate some of the breadth and variety of the global movement of texts, ideas, and people within the scientific networks of the Spanish colonies. In the next chapter, the circulation of scientific books within New Spain—and beyond—is examined. The chapter assesses the Mexican booktrade and Inquisition upon seventeenth-century scientific practice.

Chapter 5 The Circulation of Scientific Books to and from New Spain (1550-1700)

During the sixteenth century, Castilian-language works of science and mathematics were sought after throughout Europe. By mid-century Castilian had begun to replace Latin as the language of choice by Spanish authors, and these Castilian-language publications, in turn, were translated into English, Dutch, German, Portuguese, French, Italian, and Catalan. More than one thousand books and pamphlets concerning mathematics, optics, and engineering—written by Spanish authors from 1475 to 1600—are gathered in *Bibliographia Physico-Mathematica Hispanica* (Valencia, 1999), over one thousand titles in *Los impresos científicos españoles de los siglos XV y XVI* (Valencia, 1981) and another thousand, sixteenth- and seventeenth-century titles in the *Bibliographía Medica Hispanica* (Valencia, 1989).¹ The three compilations list works on astronomy and engineering, natural history and medicine, with minimal overlap. Statistics about these works show that scientific publishing more than doubled from the beginning of Philip II's reign in 1556 to his death in 1598.

Within the intellectual centres of Madrid a funding shift took place by the end of Philip III's reign (r.1598-1621). The Academia de las Matemáticas lost its secular status by moving to the Colegio Imperial de la Compañía de Jesús. Instead of royal patronage for new expeditions, many of Spain's scientific works were influenced by, or associated with, the well-networked Jesuit Order.² Funding for scientific activity, including book publications, would have been available only to members of the order. And by the mid-seventeenth century works of science written in Castilian were no

¹ López Piñero, *Bibliographia medica*, 1, 12. Spanish editions and commentaries of relevant Classical works were also included. The *Bibliographia Physico-Mathematica* (45) excludes works on mineralogy and mining, biology (botany, zoology, physiology, medicine), ethnography, and linguistics. The specific breakdown of topic areas represented by the *Bibliographia* are: natural philosophy, astronomy, arithmetic, navigation, cosmography, calculations, military arts, astrology, mathematics, magic, architecture, metaphysics, calendrics, cosmology, encyclopedias, and geometry.

² Víctor Navarro Brotóns, "Tradition and Scientific Change in Early Modern Spain: the Role of the Jesuits," in *Jesuit Science and the Republic of Letters*, ed. Mordechai Feingold (Cambridge: MIT Press, 2003), 331.

longer being translated in significant numbers. Nevertheless, Spain's overseas territories during this century were highly receptive to books and astronomical instruments from Europe—scientists in Spanish America had been engaged in producing works of new knowledge since the early days of expansion and settlement. Indeed a steady circulation of books between Spain and New Spain made the great metropolis of the seventeenth century, Mexico City, an extension of the Spanish book market.³

By the year 1600 Mexico City sustained more than fifty dedicated booksellers and printers, and at least another forty-six general merchants also sold books in their shops.⁴ And between 1550 and 1700 Mexico City printers produced more than two hundred works relating to mathematics or science. Precise numbers are impossible to gauge, but I have identified 238. There were few reprints of scientific works, as the extensive importation of books from Europe and Spain made printing works by the local writers more economically worthwhile for Mexican printing houses than typesetting previously published European imprints.

Officials and private individuals transported Mexican imprints on science overland to the Viceroyalty of Peru, overseas to Europe, or to missions in the Pacific.⁵ In c.1650 and 1645, Diego Rodríguez sent his *Logaritmos* to Francisco Ruiz Lozano at the University of Lima as well as to Claude François Milliet Dechales in Marseille; in 1676 and 1692 Sigüenza y Góngora sent his observations to José Zaragoza in Spain and Admiral Pez (likely aboard a ship on the Atlantic); and in 1667 Alexandro Favián shared his manuscript *Tautología Extática* with Athanasius Kircher in Rome. These scientists participated in networks of long-distance correspondence that regularly transported books in both directions. Products of the many printing centres of Europe outnumbered those produced in Spain's overseas territories; nevertheless, European scientists, especially book collectors, showed a clear interest in the observations made by colleagues overseas.

Though scholars and bibliographers since the eighteenth century have shown that a lively transoceanic booktrade existed within the Spanish territories, this area of research began in earnest during the 1950s. Irving Leonard produced several

³ Trabulse, "Libros."

⁴ González Obregón, *Libros y Libreros*, 554-57.

⁵ Several eighteenth-century documents that I was able to view at Santo Tomas University Archive (Manila) showed requests to a Dominican chapterhouse in Mexico City for another shipment of books to be sent. Among the same sets of documents were Jesuit meteorological reports and weather forecasts.

bibliographic studies, while Huguette and Pierre Chaunu published their findings of shipping documents from the Archivo de Indias in Seville.⁶ Currently Pedro Rueda in Spain and Nora Jiménez in Mexico, historians of the book trade, have produced comprehensive studies of the imported books in circulation within New Spain.⁷ John Crossley has described the extant collection of Hernando de los Ríos Coronel (1559-1623) held at the University of Santo Tomas in Manila.⁸ While Spanish publications have been quantitatively surveyed by López Piñero's research group at the University of Valencia and Elías Trabulse has produced an anthology and various studies of the scientific texts in New Spain during the early modern period, we still lack analytical studies of the scientific books contained in novohispanic and transatlantic book inventories before 1700.⁹

This chapter meets the need for analytical studies of scientific books in New Spain. It identifies scientific works in circulation across the Atlantic during the seventeenth century by using a selection of booksellers' and private collections inventoried between 1640 and 1690. It addresses two questions for a new assessment of the circulation of ideas between New Spain and Europe: Which scientific books were available in Mexico City during the seventeenth century,¹⁰ and what role did the Spanish and the Mexican Inquisitions play in reading and censoring these works?

In the first section, I discuss some major works of mathematics produced in Spain that circulated throughout the empire and then identify some scientific works produced in New Spain that also traveled to Spain. The second section inventories titles produced in New Spain during the sixteenth and seventeenth centuries that

⁶Chaunu and Chaunu, *Seville*, VII. Also see Irving Leonard's studies of the trade in Spanish books with Mexico and Peru: Irving Leonard, "On the Mexican Book Trade, 1683," *Hispanic American Historical Review* 27, no. 3 (1947): 403ff; "On the Mexican Book Trade, 1576," *Hispanic Review* 17, no. 1 (1949): 84ff. "On the Cuzco Book Trade, 1606," *Hispanic Review* 9, no. 3 (1941): 359ff.

⁷Nora Edith Jiménez, "Comerciantes de libros en la Nueva España en el siglo XVI," in *Impresos y libros en la historia económica de México (siglos XVI-XIX)*, ed. María Pilar Gutiérrez-Lorenzo (Guadalajara: Universidad de Guadalajara, 2007), 17ff; Cervera Jiménez, "Ciencia Europea," 161ff; Pedro Rueda Ramírez, "El comercio de libros con América en el siglo XVII: El Registro de Ida de Navíos en los años 1601-1649," *Tiempos Modernos: Revista Electrónica de Historia Moderna* 4, no. 11 (2004): unnumbered.

⁸John Crossley, "Una biblioteca en Las Filipinas en 1611," *Cuadernos para la Investigación de la Literatura Hispánica* 35 (2010): 189ff; Irving Leonard, "One Man's Library, Manila, 1583," *Hispanic Review* 15, no. 1 (1947): 84-100.

⁹López Piñero, Bujosa Homar, and Navarro Brotóns, *Impresos científicos Españoles*; Salavert Fabiani, "Imprenta," 233ff.

¹⁰Extant inventories of Jesuit libraries in New Spain from 1767 would offer a representative sample of how many European works of early modern science were imported from Europe into Mexico City during these years.

included references to mathematics, calendrics and timekeeping, fort building, engineering, surveying, sailing, and architecture, and discusses the influence of the Mexican Inquisition on the local production of scientific works.¹¹ Works of alchemy and astrology,¹² botanical works and descriptions of animals, and reports of natural disasters are also listed as sources for early modern ideas about the structure of the earth and theories of first-hand and “virtual” observation. Section three comprehensively identifies the scientific works of Melchor Pérez de Soto’s private library which, like many other significant book collections in New Spain, was composed primarily of works printed in Europe. While the existence of Pérez de Soto’s book collection is well-known by scholars of colonial New Spain, its titles have not been analysed for content related to early modern science. The Mexican Inquisition’s inventory of Pérez de Soto’s books suggests that the circulation of particular ideas about astronomy, astrology, and the methods of producing knowledge about the physical world on both sides of the Atlantic during the seventeenth century included a wide range of technical as well as occult materials.

A focus on inventories of printed books as evidence for scientific activity has a number of advantages and limitations. Printed books are not necessarily easier to track than the more numerous manuscript sources, but they are more likely to have been recorded by eighteenth and nineteenth-century bibliographies and may be found within online databases such as the Catálogo Colectivo de Impresos Latinoamericanos and Iberian Books.¹³ Focusing on printed books also leaves out the quantities of navigational and cartographic documents produced for the Council of the Indies and the Casa de la Contratación (for example, the *relaciones geográficas*) as well as letters written to the Crown by early explorers and other correspondence networks.

¹¹ Juan de Zumárraga the Archbishop of Mexico City obtained the royal permission in Spain to establish the printing press of the Americas in 1539 for the purposes of evangelization. The very first titles printed were bilingual catechisms and grammars of indigenous languages for clergymen and missionaries to prepare for their duties in New Spain even before leaving Spain, such as the *Breve y Compendiosa Doctrina Cristiana en lengua Mexicana y Castellana* (México, 1539). Based on the earliest word lists for those studying the many and varied native languages of New Spain, the vocabulary they learned dealt in large part with catechesis. Printer Juan Pablos of the Cromberger firm in Seville, Spain set up the first printing press in the Americas under the aegis of the Church and the viceregal court near the palace and Cathedral. For a growing catalogue of the oldest, extant books printed in the Americas see: “Primeros Libros de las Américas: Impresos Americanos del siglo XVI en las Bibliotecas del Mundo” <http://primeroslibros.org>

¹² For lucid studies of the genres frequently deemed “occult” by the Spanish Inquisition see: William Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton: Princeton University Press, 1994), 134ff; Lawrence Principe, *The Secrets of Alchemy* (Chicago: University of Chicago Press, 2013), 107ff.

¹³ To search the catalogues see: ccila.ucr.edu & <http://iberian.ucd.ie/>

Letters containing astronomical and geographical observations crossed the oceans and circulated within learned communities, such as those addressed to Athanasius Kircher or the Duchess of Aveiro. Many other little known or lost manuscripts produced by scientists in New Spain fall beyond the purview of this analysis.

The Circulation of Scientific Works to and from New Spain

Mathematics was critical to many scientific disciplines. The reliance of Spanish scientists upon their training in mathematics and in their particular craft or use of instruments were viewed as essential for solving the problems of an expansive empire. Works of mathematics produced in Spain were well regarded throughout Europe and circulated throughout the empire. Some mathematical works were also produced in New Spain. During the reign of Philip II and well into the seventeenth century, publishing in the language of Castile enabled authors to reach readers of scientific and mathematical works. Unlike at Spanish universities where Latin was spoken and read inside the classroom, the Academy of Mathematics in Madrid was required to teach and publish in Castilian.

The academy newly established in December of 1582 by Philip and directed by his preferred architect Juan de Herrera, as well as other engineers, architects, and mathematicians, was located in a building that directly faced the entrance to the Palacio Real. In 1625, four years after Philip III's death, the academy's courses began to be taught exclusively by Jesuits. During the reign of Philip IV, in 1629, what remained of the academy moved to the Jesuit Colegio Imperial.¹⁴ Cosmographer and academic Chair of the Art of Navigation, Rodrigo Zamorano wrote a dedication to the 1576 edition of Luciano de Negrón's *Los seis libros primeros de la Geometría de Euclides* which illustrates the mathematical attitudes of this period. In it, he states that all scientific endeavours depended upon geometry: "Astronomy could prove little knowledge regarding the movements and eclipses of the Sun and Moon, if all

¹⁴ From being Philip II's pet institution located right in front of his Madrid palace, the mathematical scientific community of Madrid soon changed to become the domain of the Jesuits. The Academia de Matemáticas closed and many of its students and staff moved to the Colegio Imperial south of the Plaza Mayor. Many historians have noted the fondness of Philip II for promoting the sciences during his reign and the absence of such enthusiasm during the reigns of his successors with the sharpest decline at the end of the seventeenth century when the economy and monarchy were unstable. Raquel Álvarez Peláez, "Felipe II, la ciencia y el nuevo mundo," *Revista de Indias* 59, no. 215 (1999): 18.

[Astronomy's] demonstrations were not made using Geometry.”¹⁵ Not content to leave the significance of studying Geometry to its applications for Astronomy alone, Zamorano discusses its centrality to architecture, painting, sculpture, civil and military engineering, optics, cosmography, and natural philosophy.

Geometry played a central role in other contemporary manuals as well. For example, courtier and military official Juan Alfonso de Molina Cano argued that his readers ought to teach their children mathematics from the time that the little ones could read and write. As he states in his *Descubrimientos geométricos* (Antwerp, 1598):

Because the admirable discipline of Geometry is essential to all types of persons, I dare to recommend to those who govern republics, that learned persons be employed to read and teach [Geometry] to the public, and to persuade parents... with the opportunity to educate their children well [in Geometry] once they know how to read, write, and count.¹⁶

Molina Cano stressed that in addition to the utility of such study from an early age, children would grow up without the vice of dishonesty because they would have become accustomed to dealing with proofs and truths which are based upon other truths.¹⁷ Similarly, Ginés de Rocamora y Torrano, a public official in Murcia, stated in the first chapter of his *Sphera del Universo* (1599) that it is desirable to make an effort to “conquer science which brings so many benefits, in particular Mathematics...which imparts as much about the evidence of truth as about the calibration of the balance in which the evidence is weighed, as about the measurements used to weigh it... so much so that, after our holy faith, this world has nothing truer than Mathematics.”¹⁸ These authors characterised Mathematics as a means of accessing unalloyed truth and made “the truth” a motif in their works.

Juan Pérez de Moya's work *Arismética Práctica* [sic] y *Especulativa* (1562) is the most important sixteenth-century Spanish mathematics treatise.¹⁹ The work's

¹⁵ From Pedro López de Montoya's *Libro de la buena educación y enseñanza de los nobles* (Madrid, 1595), in chapter XVI entitled “Which Sciences Should be Taught to Nobles” he writes: “It is convenient for all nobles to enjoy some knowledge of all the sciences.... For those who have more time and the proper disposition a thorough study of the mathematics is in order.” M.I. Vicente Maroto and Mariano Esteban Piñero, *Aspectos de la ciencia aplicada en la España del Siglo de Oro* (Madrid: Junta de Castilla y León, 2006), 21-22.

¹⁶ *Ibid.*, 23.

¹⁷ *Ibid.*

¹⁸ Vicente Maroto and Esteban Piñero, *Aspectos*, 23.

¹⁹ López Piñero, *Ciencia y técnica*, 176.

clear and precise structure as well as an appealing writing style made it popular even outside of the Iberian Peninsula. The dialogue between Sofronio and his interlocutor Antímaco, who plays the role of a sceptic, allows the text to stand-in for the instructor himself and amuses the readers as they learn algorithms to solve arithmetic and geometric problems. Pérez de Moya studied at the venerable University of Salamanca and afterwards resided in the newer university town of Alacalá de Henares, but he was not employed by the university; nevertheless, he was a prolific writer of mathematical treatises and evidence exists that he taught pupils. Simon Stevin (1548-1620), a Flemish mathematician and engineer who coined what was to become the scientific vocabulary for the Dutch language, recommended the study of Pérez de Moya's work for, among other things, its discussion of cubic roots. Within Spain the work appeared in fifteen editions during the seventeenth century.²⁰

Pedro Nunes—considered one of the great lights of Iberian mathematics during the sixteenth century—chose to publish in Spanish when his native language was Portuguese.²¹ Nunes, a professor at the University of Coimbra, held a royal appointment as Cosmógrafo Mayor. The publication of the Castilian edition of Nunes's *Libro de Álgebra en Arithmética y Geometría* in 1567 in Antwerp illustrates the international arena of Iberian publishing in addition to the reach of mathematical works published in Spanish.²²

In addition to books on mathematics, Castilian-language works that concerned navigation also circulated in the Atlantic world. The problem of establishing the latitude and longitude of urban centres in the Spanish territories was a frequent topic of publication during the sixteenth century. Juan López de Velasco's *Geografía General de las Indias* (1574) included instructions for making astronomical observations that would provide the necessary figures for calculating the reference data to relate the cities of the New World to those of Europe. These figures would in

²⁰ Juan de Ortega's *Tratado subtilissimo de Aritmética y Geometría* (1534, 1537, and 1542) with its method for finding square roots was translated into French just after the first Spanish edition and soon afterward published in Italy. See: *Materiales* 12-14.

²¹ López Piñero, *Ciencia y técnica*, 17. During the Middle Ages, Portugal had dynastic ties to individual Spanish kingdoms. Between 1469 and 1492, Isabel and Ferdinand unified the kingdoms into a single Spanish Crown, and from 1580 to 1640 Portugal and its overseas possessions were politically linked to Spain by shared monarchs through the Iberian Union.

²² Philip II established a half dozen research institutes to focus primarily on engineering and navigation. He also diversified the skillset of his new science centres by contracting specialists from the outer reaches of his European territories—Flanders, Italy, and Portugal. In his later years, health and medicine became an increasing concern to him: he established specialized gardens and a distillation lab at his Aranjuez palace for medicinal plants gathered in the Americas and Philippine Islands.

turn be applied to the production of more accurate maps; the *piloto mayor* at Casa de la Contratación in Seville was responsible for regularly and systematically revising the *padrón real* (royal chart) with new data from shipping logs and charts. Maps were politically significant, and being able to demonstrate their accuracy—by synthesising the mathematical calculations contained in a collection of recent ship’s logs—was essential to reducing their contestation.

A portion of the works that crossed the Atlantic dealt with the latest humanistic thought as well as the applied sciences, while many more were religious and literary texts. One finds a variety of reading tastes within passengers’ shipping lists of personal effects. Alongside the sonnets of Lope de Vega and stories of saints were books by Descartes and guides to medicine as well as veterinary manuals that emphasised how to care for large domesticated animals, for example the works of *albeitería* (veterinary medicine), introduced into the Americas by the Spanish.²³

²³ Considering the culture of horsemanship and rodeo still alive in Mexico today, it is not surprising that veterinary manuals specifically about the anatomy, training, and care of horses were well represented among Spanish publications during this period.

Figure 5.1: “Record of the books which I take with me...upon these...galleons for Don Manuel de Bañuelos y Sandoval” 1669, AGI Contratación 674, ff.11-12.²⁴

²⁴ Note the work *Redondo de Albeytteria* on the right-hand column, two-thirds of the way down the list. Such works of veterinary medicine often focused mostly on the care of horses.

Some books traversed the Atlantic several times as manuscript copies and published borrowings. Francisco Hernández's manuscripts, for example, circulated in private copies among European botanists and physicians before the text appeared in print, as shown in chapter one.²⁵

Among the travelers carrying books were surgeons and medical doctors. Their reference books included practical guides to treating common illnesses of transoceanic crossings as well as wounds of battle. From the early days of Spanish settlement in the Americas, ships' doctors encountered new remedies and even new illnesses found in the New World. Among the wills and testaments of doctors and surgeons who died on board Spanish ships, there are at least nine sets of inventories which indicate the instruments and texts which aided them in their work. The ship's surgeons treated sailors' ailments with European and New World *materia medica*. Some of the books listed in the collections of ship's surgeons include: Robledo, *de Cirugía*, Fragoso, *de Cirugía Añadido*; Joanes el Viejo, *de Cirugía*; *Magia Natural*; *Tratado de Apostemas*; *Tarea o Todo de Cirugía*; *Tratado de Peste*; Fray Andrés de León, *Anatomía*; *Secretos del Reverendo Don Alejo Piamontés*; Fragoso, *de Cirugía*, *Instrucción de Enfermos*; *Terapéutica*; *Compendio de Toda la Cirugía*; and *Tratado Breve de Flebotomía*.²⁶

Except in the case of colonial reprints, European publications—whether in bulk for booksellers or as smaller personal collections—would have been transported in trunks or among the personal effects of passengers traversing the Atlantic at regular six-monthly intervals. Once at Veracruz, both civil and Inquisition officials inspected the ships' cargo before allowing goods to be stored at warehouses or transported overland by mule carts.²⁷ Among the books cleared by Inquisition officials were those that found their way to the first academic library in the New World, the Colegio de Santa Cruz de Tlatelolco.

Founded in 1533, Santa Cruz de Tlatelolco held some of the earliest book collections sent to Mexico City by Spanish settlers. Its collection contained works printed in Antwerp, Louvain, Venice, Paris, Lyon, Salamanca, and Seville, Basel,

²⁵ The earliest selections to appear in print in Mexico City were made by the friar Francisco Ximénez c.1600 who received a handwritten copy from a friend who had acquired the text from someone who had copied it at the Escorial Library in Spain.

²⁶ Rodríguez-Sala, *Cirujanos del mar*, 42-43.

²⁷ Leonard, *Books of the Brave*, 175.

Alcala de Henares, Rome, and Granada.²⁸ The presence of European publications there suggests that early novohispanic book collections of this period reflected pan-European intellectual interests, and demonstrate the effectiveness of the Frankfurt and Medina del Campo book fairs and other bespoke methods for obtaining books.

Books were also printed in New Spain within twenty years of Cortés' arrival. A family of German printers, the Crombergers, established the first press in the Americas in 1539 in Mexico City.²⁹ During the first thirty years, the American presses mainly produced official documents, catechisms, and grammars of indigenous languages.³⁰ Fledgling European missionaries relied on these grammars for communicating in a variety of native languages. Alonso de la Veracruz's *Recognitio Summularum* (Mexico City, 1554) and *Dialectica Resolutio* (Mexico City, 1554) are the earliest books of mathematics printed in the Americas (see Table 5.1). Mathematical and scientific publications made knowledge about the lands of New Spain available to overseas and local readers.³¹ Reprinting European books was not strictly necessary as early conquistadors, missionaries, and other colonizers brought their own collections with them, and Spanish book sellers had a large audience for their books in the colonies. The presses published original material about New Spain, local events, and happenings in the rest of the Spanish colonies. Religiously themed works outnumber the histories (local and otherwise), which in turn, outnumber the technical (math and science) related works.

Table 5.1: Mathematics Books Printed in Mexico City before 1600

Alonso de la Vera Cruz	<i>Recognitio Summularum</i>	1554
Alonso de la Vera Cruz	<i>Dialectica Resolutio</i>	1554

²⁸ Michael Mathes, *Santa Cruz de Tlatelolco: la primera biblioteca académica de las Americas* (México: Secretaria de Relaciones Exteriores, 1982), 84-89.

²⁹ For a study of the Crombergers in Spain see, Griffin, *Crombergers*, 82.

³⁰ Garone has argued that before 1600, native language printing—grammars, catechisms, and educational texts—were the primary motivation for establishing printing presses in New Spain. Marina Garone Gravier, *Historia de la tipografía colonial para lenguas indígenas* (México: Investigaciones Superiores en Antropología Social, 2013), 21.

³¹ By “scientific publications” I am referring broadly to books concerning: navigation, explorers' reports, astronomy, astrology, machines, clocks and other instruments, mathematics, music, mineralogy, architecture, engineering, agriculture, botany, animals, medicine, anatomy, geography, hydrology, accounts of earthquakes, alchemy, cooking, magic, and books of “secrets.” Other kinds of new knowledge such as ethnographies and studies of indigenous languages could also be included but are beyond the focus of this thesis.

Juan Diez Freyle	<i>Sumario</i>	1556
	<i>Compendioso</i>	
Alonso de la Vera Cruz	<i>Phisica, Speculatio</i>	1557
Francisco de Toledo	<i>Introductio in</i>	1578
	<i>Dialecticam</i>	
Francesco Maurolico	<i>De Sphera</i>	1578, Reprint
Francesco Maurolico	<i>Computus</i>	1578, Reprint
	<i>Ecclesiasticus</i>	
Diego García de Palacio	<i>Diálogos Militares</i>	1583
Diego García de Palacio	<i>Instrucción Náutica</i>	1587

Source: Burdick, *Mathematical Works* 9.

Mexican imprints occasionally made their way into notable book collections outside the Spanish empire.³² When Hans Sloane returned to London from his visit to Jamaica in 1687, for example, he carried with him Mexican imprints (Table 5.2). Indeed Sloane appears eager to purchase books printed in New Spain because a quick glance at their titles reveals that, despite the relative abundance of scientific and mathematical works published in Mexico City during the seventeenth century (see Table 5.3 and Table 5.4), Sloane bought a number of preachers' sermons. Perhaps novohispanic popular culture interested him. By the time of his death in 1753 he had collected at least twenty-six of these books published in New Spain, suggesting a ready availability of such imprints to collectors and scientists in Europe (see Table 5.2). When the demand for Spanish navigational texts began to wane in the seventeenth century, English collectors and readers of scientific works took a keen interest in the medicinal plants of the Americas, specifically novohispanic botanical works.³³

³² European translations and extracts of works produced in New Spain and Peru were more numerous in the book collections of Europe and the English colonies than the original Mexican or Peruvian imprints themselves. See note 30.

³³ Navarro Brótons and Ibarra, *Bibliographia Physico-matemática*, 17-18. Also see page 39 note 55 of this thesis. From the mid-seventeenth century, works of Peruvian metallurgy such as Álvaro Alonso Barba's *Arte de metales* (Madrid, 1640) also earned attention outside of the Spanish empire; more than twenty editions came out—mostly translations into English, German, French and Latin—within a century of its publication. Barnabas has argued that the work was more influential in Northern and Central Europe than it was elsewhere based on evidence of its many reprints, see J.M. Barnadas, *Álvaro Alonso Barba (1569-1662): investigaciones sobre su vida y obra* (La Paz: Biblioteca Minera Boliviana, 1986), 74. Bigelow has noted that George Washington (1732-1799) owned a translation of the *Arte de metales* printed by the Pietist community in Ephrata, Pennsylvania. See: Allison Bigelow, "Mining Empire, Planting Empire: The Colonial Scientific Literatures of the Americas" (PhD Thesis, University of North Carolina, Chapel Hill, 2012), 25.

Table 5.2: Hans Sloane's Collection of Mexican Works (includes works produced in New Spain but published in Europe)

1. Dávila Padilla, Agustín. *Historia de la fundación y discurso de la prouincia, de Santiago de México...* Edición segunda. Iuan de Meerbeque: Brusselas, 1625.
2. Bocanegra, Mathías de. *Auto General de la Fee celebrado... en la muy noble, y muy leal ciudad de México...* México, [1649.]
3. Aguiar y Acuña, Rodrigo de. *Sumarios de la Recopilación general de las leyes, ordenanças... para las Indias Occidentales, Islas, y Tierra Firme del mar Océano...* México, 1677.
4. Moro, Gerardo. *Informe en Derecho, sobre que la Compañia de el Real Asiento de la Gran Bretaña, establecida ... para la introduccion de Esclavos Negros, en estas Indias....* México, 1724.
5. Hernández, Francisco. *Quatro Libros de la Naturaleza, y Virtudes de las plantas, y Animales que estan recevidos en el uso de Medicina en la Nueva España...* México, 1615
6. Vetancourt, Agustín de. *Arte de Lengua Mexicana...* México, 1673.
7. Avendaño Suárez de Sousa, Pedro de. *Sermón del glorioso abad S. Bernardo...* Maria de Benavides: México, 1687.
8. Avendaño Suárez de Sousa, Pedro de. *Sermón que en la fiesta que celebra la Compañia de Bethlem...* Maria de Benavides: México, 1688.
9. Avendaño Suárez de Sousa, Pedro de. *Sermón de la esclarecida virgin...y... Sta Barbara...* J. J. Guillena Carrascoso: México, 1697.
10. Avendaño Suárez de Sousa, Pedro de. *Sermón del primer dia de Pasqua, del Espíritu Santo, en su hospital de México...* J. J. Guillén Carrascoso: México, 1697.
11. Argüello, Manuel de. *Sermón de la Dominica Septuagésima, en la S. Iglesia Cathedral de la ciudad de México...* M. de Benavides: México, 1691.
12. Argüello, Manuel de. *Sermón moral al Real Acuerdo de México al tiempo que tomó posesion con publica entrada ... [Virrey] Joseph Sarmiento Valladares ...* J. J. Guillena Carrascoso: México, 1697
13. Martínez de la Parra, Juan. *Sermón Panegyrico a las virtudes... de el Apostol de la India ... San Francisco Xavier...* México, 1690.
14. Martínez de la Parra, Juan. *Sermón Panegirico...elogio sacro de San Eligio Obispo de Noyons...* México, 1686.
15. Aguirre, Pedro Antonio de. *Tránsito gloriosísimo de Nuestra Señora la santissima Virgen Maria...* J. J. Guillena Carrascoso: México, 1694.
16. Narvaez, Juan de. *Catedrático de Sagrada Escripura Sermón que en la Celebridad de la Translacion del Cuerpo del glorioso apóstol de la India S. Francisco Xavier...* México, 1694.
17. Reyes Angel, Gaspar de los. *Sermón al glorioso San Francisco de Borja...* México, 1688.
18. Nicolas, de la Trinidad. *Sermón a S. Antonio de Padua en la Rogativa, que, por el buen viage de la flota hizo la Mission...* México, 1691.
19. Florencia, Francisco de, 1620-1695. *La milagrosa invención de un tesoro escondido en un campo, que hallò un ... Cazique, y escondio en su casa...* México, 1685.
20. Congregación de N. Señora de los dolores de el Colegio de S. Pedro, y S. Pablo. *Motivos pios para adelantar la devoción...* México, [1623]
21. Servites, Order. *Breve Relación del Origen ... de la ... Religion de los Siervos de Maria ... sacados de los Anales y Historia ...* México, 1699.
22. Velasco, Alfonso Alberto de. *Renovación por si misma de la soberana Imagen de Christo*

- Señor ... que llaman de Ytzimiquilpan...* México, 1688.
23. Archicofradia del Santísimo Rosario (Puebla de los Ángeles). *Octava maravilla del nuevo mundo en la gran capilla del Rosario...* Puebla, 1690.³⁴
24. Dampier, William, 1652-1715. *A New Voyage round the World. Describing particularly, the Isthmus of America...the South Sea coasts of Chili, Peru, and México...the Isle of Guam one of the Ladrões, Mindanao, and other Philippine and East-India islands...* London: James Knapton, 1697.
25. Maesta, Cesarea. *Copia delle lettere del Prefetto della India la nuoua Spagna detta, alla Cesarea Maesta rescritte..* [n.p. 1534]
26. Espejo, Antonio de. *El viaje que hizo A. de E. en el anno de ochenta y tres: el qual con sus companeros descubrieron una tierra ... a quien pusieron por nõbre nuevo México...a la costa de Richardo Hakluyt.* Paris, 1586.
27. Morga, Antonio de. *Sucesos de las Islas Philipinas...* Mexici ad Indos, 1609.
28. Echave, Balthasar de. *Discursos de la Antigüedad de la Lengua Cantabra...* México [n.d.]
29. Ribera Florez, Dionysio de. *Relación historiada de las exequias funerales de ... Felipe II...* México, 1600.
30. Molina, Alonso de. *Aquí comienza un vocabulario en la Lengua Castellana y Mexicana...* A. de Spinosa: México, 1571.

Source: British Library, "Sloane Printed Books"
www.bl.uk/catalogues/sloane/BriefDisplay.aspx

Books also traveled from Mexico City to dignitaries in Europe. For example, many of the indigenous codices currently found in Europe such as the Nahuatl 'Codex Cospi' was gifted to Ferdinando Cospi in Bologna of 1665 and the Mixtec 'Vienna Codex' gifted to Holy Roman Emperor Leopold I in 1677.³⁵ Other books were produced specifically for the Spanish Crown. Viceroy Galve commissioned Sigüenza y Góngora's history (1692) of the circumnavigation of Alonso Ramírez, a carpenter-turned-pirate from Puerto Rico,³⁶ for the explicit purpose of sending the published work to the Crown. Informing Philip IV of English piracy along the coasts of New Spain was a top priority.³⁷ "Having ordered that [Ramírez] be brought to this Court [Mexico City]," the Viceroy relates,

I then commanded that a declaration relating his course and misfortunes...in such... an unprecedented navigation be taken down in writing; the strangeness...of his story prompts me to send it to Your Excellency. I have had it published so that many copies can be

³⁴ The "Chapel of the Rosary" in Puebla is a remarkable example of baroque artwork produced by indigenous artisans.

³⁵ Daniela Bleichmar, "Seeing the World in a Room: Looking at Exotica in Early Modern Collections," in *Collecting Across Cultures: Material Exchanges in the Early Modern Atlantic World*, eds. Daniela Bleichmar, et al. (Philadelphia: University of Pennsylvania Press, 2011), 18.

³⁶ López Lázaro has identified Ramírez's captor, in 1687 off the coast of Macau, as none other than privateer-naturalist William Dampier (1651-1715), see López-Lázaro, *Misfortunes*, 31.

³⁷ Archivo Historico Nacional, Sección Nobleza, Osuna 55, 61 quoted and translated in *ibid.*, 6.

forwarded to you in the eventuality that you should desire to distribute it amongst our friends....

The elite recipients of these gift-books from the Americas loaned them to acquaintances within learned circles.

Publishing in Mexico City provided unique opportunities for Europeans to produce new knowledge about the world, and that knowledge then crossed the Atlantic back to Spain. Shipbuilders in Mexico City's port Veracruz—and later Navidad-Acapulco—used shipbuilding manuals to train their apprentices and maintain a seaworthy transoceanic fleet. One of the first books exclusively on the subject of shipbuilding, Diego García de Palacio's *Instrucción náutica, para el buen uso y regimiento de las naos*, printed in Mexico City in 1587, met that need. Shipyards in the Caribbean, such as at Havana, also needed the *Instrucción náutica*. Caribbean shipwrights relied upon Mexico City's publications until 1707 when the Havana printing house was established. Other notable examples of science or "new knowledge"-themed Mexican imprints arrived on the Iberian Peninsula during the sixteenth and seventeenth centuries and have since been incorporated into Spain's Biblioteca Nacional (see Table 5.3).³⁸ Clergymen-linguists produced a vast array of language learning aids for missionaries, translators, lawyers, and governors in their interactions with the diverse native populations of the Americas and the Pacific. These grammars and lexicons frequently sought to transmit some knowledge of specific cultures, such as the sayings of Nahuatl elders, although dedicated ethnographic accounts maintained a genre of their own and were at times viewed by censors as politically dangerous.³⁹ Mexico City's publications served local readerships within Spanish America and were also shipped, in lesser numbers, to Europe and Pacific communities.

³⁸ "Unlike the [Mexican imprints] housed by the great libraries in the United States, it is highly probable that the majority of those books which arrived on the Iberian Peninsula did so in a 'natural' way, within trunks and crates belonging to peninsular 'Spanish' and *criollo* travellers—of the 16th and 17th centuries—who journeyed from the American kingdoms as subjects of the same Crown." Solange Alberro, "Presentación," in *Repertorio de impresos mexicanos en la Biblioteca Nacional de España, siglos XVI-XVII*, ed. Victor Cid Carmona (México: Colmex, 2004), 13. For a catalogue of U.S. repositories holding sixteenth- and seventeenth-century Mexican imprints see: José Pascual Buxó, *Impresos novohispanos en las bibliotecas públicas de los Estados Unidos de América (1543-1800)* (México: UNAM, 1994), 15ff.

³⁹ Fray Juan Bautista (c1555-1613) published the sayings of Nahuatl elders in his *Huehuetlahtolli, que contiene las pláticas que los padres y madres hicieron a sus hijos...* (Ciudad de México, 1601).

Table 5.3: Selection of Mexican Imprints that arrived in Spain during the 16th and 17th Centuries

1. *Advertencias para mayor noticia de la gramatica* (Ciudad de México, 1631)
2. *Informe del Nuevo beneficio que se had dado a los metales...* por Luis Berrio de Montalvo (Ciudad de México, 1643)
3. *Alivio de mercaderes: y todo genero de gente, para facilidad de las cuentas...* por Pedro Aguilar Gordillo (Ciudad de México, 1610)
4. *Aqui comienza un vocabulario en lengua Castellana y Mexicana...* por Fray Alonso de Molina (Ciudad de México, 1555)
5. *Arte de lengua Mexicana...* por Horacio Carochi (Ciudad de México, 1645)
6. *Arte de lengua Mexicana...* por Fray Agustín de Vetancourt (Ciudad de México, 1673)
7. *Arte de la lengua Tagala...* por Fray Agustín de la Magdalena (Ciudad de México, 1679)
8. *Arte mexicano...* por Diego Galdo Guzmán (Ciudad de México, 1642)
9. *Astro mythologico politico...* por Alonso de Alavés Pinelo (Ciudad de México, 1650)
10. *Breve aritmetica...* por Benito Fernández Belo (Ciudad de México, 1675)
11. *Carta athenagorica de Juana Inés de la Cruz* (Puebla, 1690)
12. *Diálogos militares...* Diego García de Palacio (Ciudad de México, 1583)
13. *Discursos de la antigüedad de la lengua Cantabra Bascongada...* por Baltasar de Echave (Ciudad de México, 1607)
14. *Doctrina Cristiana en lengua castellana y zapoteca...* por Fray Pedro de Feria (Ciudad de México, 1567)
15. *Exaltación magnífica de la Betlemitica Rosa de la mejor americana...* por Pedro Muñoz de Castro y otros (Ciudad de México, 1697)
16. *Grandeza Mexicana...* por Bernardo de Balbuena (Ciudad de México, 1604)
17. *Historia de la Provincia de la Compañía de Jesus de Nueva-España...* por Francisco de Florencia (Ciudad de México, 1694)
18. *Libra astronomica y philosophica...* por Carlos de Sigüenza y Góngora (Ciudad de México, 1690)
19. *Mapa de las once Iglesias Cathedrales en estos Reynos de Nueva-España...* por Gonzalo de Paz (Ciudad de México, 1668)
20. *Memorial de los sucedido en la ciudad de México, desde el día primero de Noviembre de 1623, hasta quinze de Enero de 1624...* por Magino Sola (Ciudad de México, 1652)
21. *Parayso Occidental...* por Carlos de Sigüenza y Góngora (Ciudad de México, 1684)
22. *Primera parte de los problemas y secretos maravillosos de las Indias...* por Juan de Cárdenas (Ciudad de México, 1591)
23. *Quatro libros de la naturaleza y virtudes de las plantas y animales...* por Fray Francisco Ximénez (Ciudad de México, 1615)
24. *Reducción de oro...* por Francisco Fagoaga (Ciudad de México, 1700)
25. *Reduciones de plata...* por Manuel de Zuaza y Aranguren (Ciudad de México, 1697)
26. *Relación cierta, y verdadera de los que sucedió y ha sucedido en esta Villa de Guadalcazar Provincia de Tehuantepeque...* por Cristóbal Manso de Contreras (Ciudad de México, 1661)
27. *Relación de los mártires del Japon del año de 1627...* por Pedro Morejón (Ciudad de México, 1631)
28. *Relación universal legítima y verdadera del sitio en que esta fundada la muy noble, insigne, y muy leal Ciudad de México...* por Fernando de Cepeda (Ciudad de México, 1637)
29. *Repertorio de los tiempos, y historia natural desta Nueva España...* por Enrico Martínez (Ciudad de México, 1606)
30. *Sitio, naturaleza y propiedades de la Ciudad de México...* por Diego Cisneros (Ciudad de México, 1618)
31. *Spicilegio de la calidad y utilidades del trigo que comunmente llaman blanquillo...* por Ambrosio de Lima y Escalada (Ciudad de México, 1692)
32. *Teatro Mexicano...* por Fray Agustín de Vetancourt (Ciudad de México, 1698)
33. *Tesoro de Medicinas para diversas enfermedades...* por Gregorio López (Ciudad de México, 1674)

34. *Tractado breve de medicina...por Agustín Farfán* (Ciudad de México, 1592)
35. *Tratado del estado de las Islas Philipinas...por Jerónimo Bañuelos y Carrillo* (Ciudad de México, 1638)
36. *Viaje de America a Roma...por Fray José de Castro* (Ciudad de México, 1690)
37. *Vocabulario en lengua Castellana y Mexicana...por Fray Alonso de Molina* (Ciudad de México, 1555 & 1571)

Source: Cid Carmona, *Repertorio de impresos mexicanos en la Biblioteca Nacional de España*.⁴⁰

Some of the notable texts listed above include Sigüenza y Góngora's *Libra Astronómica* (in bold), a grammar of a language indigenous to the Philippines, and a work about a particular variety of wheat. The various works of medicine and metallurgy suggest that these were two areas of knowledge where authors based in New Spain made particular contributions. Sor Juana's "Carta Atenagórica" cannot be overlooked; in her reply to the Archbishop of Mexico City, who had critiqued her extensive library (see Figure 5.2), she defended women's intellectual attainments.⁴¹ Mexico City intellectuals as well as technicians had specialty interests in scientific and mathematical works and supported the local production of these works (see Table 5.4 and Table 5.5).

⁴⁰ Book historian, Victor Cid Carmona, has published a list of 214 Mexican imprints found today in the National Library of Spain which he believes arrived during the early modern period: *Repertorio de impresos mexicanos en la Biblioteca Nacional de España, siglos XVI-XVII* México: Colmex, 2004. Cid Carmona does not categorize the titles according to their subject areas, nor does he identify the books with "scientific" content; the selection above is my own. The titles in bold are particularly representative of what I am referring to as the "new knowledge" which intellectual communities produced in New Spain between 1535 and 1700.

⁴¹ Scholars have postulated that Sor Juana's library included anywhere from two to ten thousand works and would have represented a significant investment of resources. She resided in a spacious suite at the Convento de San Jerónimo in central Mexico City. Besides music and poetry, she was fond of scientific pursuits; she owned clocks, globes and telescopes in addition to books. At least two portraits of the nun show Athanasius Kircher's works on the bookshelves beside her. See Elías Trabulse, "El universo científico de Sor Juana Inés de la Cruz," *Colonial Latin American Review* 4, no. 2 (1995): 45; Findlen, "A Jesuit's Books," 248ff.

Figure 5.2: Portrait of Sor Juana Inés de la Cruz (1648-1695) in her personal library.

Table 5.4: Selected Works on Mathematics and the Sciences published in Mexico City 1553-1700

1. Díez Freyle, Juan. *Sumario compendioso de las cuentas de plata y oro*. 1556
2. Veracruz, Alonso de la. *Phisica, speculatio...* 1557
3. Bravo, Francisco. *Opera medicinalia...* 1570
4. López, Alonso. *Summa y recopilación de cirugía...* 1578
5. Farfán, Agustín. *Tractado breve de anatomía y cirugía...* 1579
6. Suárez de Peralta, Juan. *Tratado de la caballería, de la gineta y brida...* 1580
7. Casas, Gonzalo de las. *Libro intitulado arte para criar seda...* 1581
8. García de Palacios, Diego. *Diálogos militares de la formación de personas, instrumentos y cosas necesarias...* 1583
9. García de Palacios, Diego. *Instrucción náutica...* 1587
10. Cárdenas, Juan de. *Primera parte de los problemas y secretos maravillosos de las Indias*. 1591
11. Farfán, Agustín. *Tractado breve de medicina y cirugía...* 1592
12. Brambila de Arriaga, Antonio. *Lunarios...* 159[5]

13. López de Hinojosos, Alonso. *Summa y recopilación de cirugía...* 1595
14. Echedoyen, Felipe. *Tablas de reducciones de monedas...* 1603
15. Farfán, Agustín. *Tractado breve de Medicina...* 1604
16. Martínez, Enrico. *Discurso sobre la mana de los planetas Júpiter y Saturno...* 1604
17. Barrios, Juan de. *De la verdadera medicina...* 1607
18. Aguilar Gordillo, Pedro. *Alivio de mercaderes...para facilitar de las cuentas...* 1610
19. Castañeda, Juan de. *Reformación de las tablas...de plata...* 1612
20. Ximénez, Francisco. *Cuatro libros de la naturaleza...* 1615
21. Bazan, N. *De las plantas y animales curativos de la Nueva España...* 1615
22. Paz, Pedro de. *Arte para aprender todo el menor del Arithmética sin maestro...* 1623
23. Berrio de Montalvo, Luis. *Informe del nuevo beneficio que se ha dado a los metales...* 1643
24. Correa, Juan. *De la cualidad manifiesta del mercurio...* 1648
25. Reatón Pasamonte, Atanasio. *Arte menor de la arismética...* 1649
26. Becerra, Fernando. *Tratado de la cualidad manifiesta y virtud del azogue...* 1649
27. Ruiz Lozano, Francisco. *Repertorio anual...* 1650
28. Ruiz Lozano, Francisco. *Repertorio anual...* 1652
29. Rodríguez, Diego. *Discurso ethereológico sobre el cometa...* 1652
30. López de Bonilla, Gabriel. *Discurso y relación cometográfica...* 1653
31. Ruiz, Juan. *Discurso sobre la significación de dos impresiones meteorológicas...* 1652
32. Osorio de Peralta, Diego. *Disertaciones sobre el agua de la zarza hermodáctilis...* 1668
33. López, Gregorio. *Tesoro de medicinas para diversas enfermedades...* 1674
34. Fernández Belo, Benito. *Breve aritmética militar...* 1675
35. Corro, Juan del. *Forma del nuevo beneficio de metales...* 1677
36. Escobar Salmerón y Castro, José de. *Discurso y relación del nuevo cometa...* 1681
37. Kino, Eusebio Francisco. *Exposición astronómica del cometa...* 1681
38. Sigüenza y Góngora, Carlos de. *Manifiesto filosófico contra los cometas...* 1681
39. Torre, Martín de la. *Manifiesto cristiano en favor de los cometas...* 1681
40. Evelino, Gaspar Juan. *Especulación astrológica y physica de la naturaleza de los cometas...* 1682
41. Oliver, José. *Disertación sobre los cometas...* 1683
42. Osorio y Peralta, Diego. *Principia medicinae epitome...* 1685
43. Sigüenza y Góngora, Carlos. *Libra astronómica...* 1690
44. Lima y Encalada, Ambrosio de. *Spicilegio de la calidad y utilidades del trigo...* 1692

Source: Francisco de Solano *Las Voces de la Ciudad: México a través de sus impresos, 1553-1821* (Madrid, 1994) p. 120-123, 141, 151-152.

Table 5.5: Books produced in Mexico City that Appear in the “Memorias de Libros” with number of Appearances

Alonso López de Hinojoso	Libro de Medicina	1578	1
Alonso López de Hinojoso	Suma y Recopilación de Cirugía	1595	3
Agustín Farfán	De Cirugía	1579	1
Agustín Farfán	De Medicina	1579	1
Diego García de Palacios	Diálogos Militares	1583	2
Diego García de Palacios	Instrucción Náutica	1587	2
Diego García de Palacios	De Navegación	1587	2
Juan de Cárdenas	Problemas y Secretos maravillosos de las Indias	1591	3

Juan Navarro	De Música	1604	1
Enrico Martínez	Repertorio de los tiempos e historia natural de la Nueva España	1606	4
Hieronimo Descacena	Kalendarium ad usum fratrum minorum	1609	1
Antoni de Morga	Sucesos de Filipinas	1609	2
Francisco Jiménez	Virtudes de las Yervas	1615	1
Francisco Jiménez	Plantas de la Nueva España	1615	1
Diego de Cisneros	Sitio y Naturaleza de México	1617	1
Diego de Cisneros	Sitio de México	1618	1
Pedro de Paz	Arismética	1623	3
Pedro de Paz	Arte de Contar	1623	1
Juan de Cepeda	Destreza de la Milicia Cristiana	1623	2
García Garcés	Mártires del Japón	1624	1
Luis de Berrio Montalvo	Del Beneficio del Azogue	1643	3
Juan Correa	Cualidades del Azogue	1648	1
Atanasio Reaton	Aritmética	1649	3
Fernando Becerra	Tratado de la Cualidad del Azogue	1649	3
Bartolomé de Molina	Cuaderno Cartapacio de mano, que trata de cosas de las Indias	n.d.	1
Of 365 Mexican Works mentioned, 12 % relate to Maths & Sciences		Total	45

Source: O’Gorman, *Bibliotecas y librerías coloniales: 1585-1694*, 663-1005.⁴²

The presence of European books in novohispanic libraries is much better documented than the presence of Mexican imprints in Spain or elsewhere. An examination of distinguished novohispanic libraries shows that collectors had special access to rare imports presumably through a collection that originated on the Iberian Peninsula or through particular networks, such as the Jesuit procurators in the case of clerics, local acquaintances, or specialty importers. For example, Melchor Pérez de Soto obtained for his library copies of ships’ logs that should not have been in public circulation as they were officially destined for the Casa de Contración or the viceroy’s collection of data for use by the royal cosmographer of New Spain.⁴³ Though records to explain his acquisition of the rutters do not exist, it is plausible that his social circle included ships’ pilots and bookdealers.

⁴² Edmundo O’Gorman’s transcriptions of the “Memorias de Libros” do not discuss the books in any way. The selection above is my own.

⁴³ See note 64 below. As a book collector, Sigüenza y Góngora also acquired local, rare manuscripts concerning the kings of Texcoco from a friend, the son of the indigenous historian Don Fernando Alva Ixtlilxochitl. Leonard, *Baroque*, 200.

Novohispanic Book Inventories and the Mexican Inquisition

The “memorias de libros,” book inventories submitted to the Mexican Inquisition by booksellers (and private individuals), are our main source for understanding the general availability of scientific books in seventeenth-century New Spain. These inventories provide a mere sample of the books that were available for sale in Mexico City bookshops. The shop keepers, as well as the occasional owner of an interesting private library who presented their ‘memorias de libros’ to the Inquisition, likely knew which book titles were best not ‘remembered’ and may well have not mentioned a few simply to avoid further scrutiny. The Mexican Inquisition regularly distributed its flysheets announcing the titles of works it considered questionable (see Figure 5.3). Book owners were instructed on these flyers to expurgate the offending lines by drawing a line through specified words of the text. Only rarely were entire works condemned, but even in the case of an occult book or a Lutheran prayer manual, the Mexican Inquisition granted permission to specific individuals—normally members of the governing elite and clergymen—to read and publish responses to the works. The inquisition censors themselves were also required to read the works carefully in order to prepare their explanations as to why works were unsuitable.⁴⁴

⁴⁴ Martin Nesvig, *Ideology and Inquisition: the World of the Censors in Early Mexico* (New Haven: Yale University Press, 2009), 227.

Figure 5.3: “We Inquisitors Against Heresy...” AGN Instituciones Coloniales, Inquisición 12508, Vol. 678 f.220

Another notable set of book inventories held at the Archivo General de la Nación date from the 1767 expulsion of the Society of Jesus from the Spanish empire by Charles III Bourbon. The Crown perceived the Society as a too powerful state-within-the-state, and civic officials were charged with the hasty appropriation and inventory of Jesuit belongings in Spain’s territories. Book historians have concluded that the vast majority of the imported titles listed in the inventories arrived in New Spain within a century of the establishment of the Jesuits there in 1572.

Figure 5.4: Inventory of Jesuit books at San Pedro y San Pablo made upon the Expulsion of the Society in 1767. AGN Instituciones Coloniales, Temporalidades 29989, Tomo 230 f.1

Though a definitive quantitative analysis of all books sold in Mexico City bookstores is difficult, the “Memorias de libros” submitted to the Inquisition do provide book titles available for sale during specified years. Private libraries might include only one copy of a book, though booksellers likely held more than one copy at any given time.⁴⁵ The inventories demonstrate that locally produced works on mathematics and the sciences appealed to elite and non-elite readers as well as to general booksellers. A segment of all books sold in New Spain concerned scientific and mathematical subjects. Based on a sample of twenty-five seventeenth-century, non-specialist booksellers located in, or near, Mexico City, on average 15% of their books concerned mathematics or the sciences (Table 5.6). The remaining 85% are novels, poetry, theatre books, law books, mirrors of princes, grammars of European languages, works on rhetoric and writing, histories of Europe, doctrinal-theological-

⁴⁵ For a quantitative breakdown of titles from a mid eighteenth-century bookstore in Mexico City see, Olivia Moreno Gamboa, *La librería de Luis Mariano de Ibarra: Ciudad de México, 1730-1750* (México: Ediciones de Educación y Cultura, 2009), 105, Table 7.

religious works and indigenous language imprints. All of these twenty-five colonial booksellers sold books published in Europe or New Spain.

Table 5.6: Summary of 25 Book Lists submitted to the Mexican Inquisition, 17th century

No. of Inventories	Year Range	Average Percentage of books about Mathematics & Science
1	1581-1590	41%
No data	1591-1600	--
1	1601-1610	5.5%
4	1611-1620	19%
1	1621-1630	22%
1	1631-1640	4%
No data	1641-1650	--
6	1651-1660	14%
6	1661-1670	7%
No data	1671-1680	--
2	1681-1690	10.6%
3	1691-1700	16%

Source: "Bibliotecas y Librerías Coloniales, 1585-1695" *Boletín* (1939) p.662-1005.

Some books sold in New Spain were smuggled across the Atlantic. Based on the discrepancy between the numbers of scientific books identified in shipping records and those found in colonial Mexican library inventories, Elias Trabulse believes that many scientific books travelled the seas as stowaways.⁴⁶ Trabulse makes a case for interpreting these discrepancies as evidence of a black market in scientific books.⁴⁷ Although he overstates his claim, as I note below, Spanish printers and booksellers offloaded their excess and provocative publications by sending them to the colonies where they would sell for higher prices.⁴⁸

If we follow Trabulse, the contraband book trade between Spain and its colonies made occult and other works which were considered suspect by the Inquisition available to readers and collectors in New Spain. But between 1600 and 1640—when Jesuit theologian Pedro de Hortigosa's (b.1546) liberalising influence was most felt in the censor's office in Mexico City—the regulation of reading

⁴⁶ Trabulse, "Libros," 10.

⁴⁷ The author of *Don Quixote*, Miguel de Cervantes (1547-1616), illustrates the difficulties even highly literate and skilled potential travellers encountered when applying for royal permission to migrate to New Spain. The veteran soldier and author, Cervantes was denied permission to cross the Atlantic and see the Americas because he had lost the use of his left hand—an injury from the Battle of Lepanto in 1571. Disability disqualified applicants from migrating.

⁴⁸ Trabulse, "Libros," 10.

materials lulled.⁴⁹ The absence of administrative visits from the Inquisitor General in Madrid gave authors free reign. Nesvig's summary of depositions in New Spain between 1621 and 1626 shows that none dealt with prohibited books while twenty-three concerned spells (*hechizos*).⁵⁰ With the arrival of the *visitador general* in the 1660s and 1680s, a renewed interest in the heterodox books is evident from increased document production by censors.

Rather than an unbounded institution of violence, the Inquisition was a court of law run by clergymen that aimed to prevent the spread of "heresy" as defined by successive hierarchies from the Roman Curia to the Roman Inquisition to the Spanish Tribunal to the Mexican Inquisition, the latter from 1571.⁵¹ To be sure, despite its attempts at conducting legally sanctioned trials and punishments only in the rare case of a conviction, most viewed the Inquisition as a nuisance.⁵² But it was not arbitrary in its prosecutions. Nesvig points out that speaking ill of the Inquisition was not enough to merit prosecution. For example, in 1615, Ana de Aranda called the Mexico City inquisitors "nothing but a bunch of drunks and fools who do not know what they are doing or consider their own vices,"⁵³ but the Inquisition dismissed the case because she had not attacked any articles of the faith. The focused goals of the ecclesiastical court allowed individuals to insult Inquisition officials.

The Mexican Inquisition's power was felt primarily by *peninsulares* (Spanish migrants) in New Spain. From 1550 the indigenous population was protected from trial within the Inquisition by royal and papal mandates, and during the seventeenth century criollos frequently served as Inquisition book censors.⁵⁴ Of the 270 cases

⁴⁹ Nesvig, *Ideology*, 175.

⁵⁰ Ibid. Nesvig's Table 7.6 based on AGN Inq. Vol. 356, exp. 6.

⁵¹ Greenleaf explains that very few Mexican Inquisition trials resulted in a conviction: "It appears that ninety-five percent of colonial Mexico never had any contact with the Inquisition. Of the five percent who did, five-sixths never came to trial because of insufficient evidence; and of that one-sixth who were tried by the Holy Office, perhaps two percent were convicted, with one-half of one percent being executed. These figures, while deplorable to the modern man, stand out in stark contrast with the accounts of the gothic writers on the Inquisition who give a distorted picture of the institution's outreach into society." Richard Greenleaf, "Historiography of the Mexican Inquisition: Evolution of Interpretations and Methodologies," in *Cultural Encounters: The Impact of the Inquisition in Spain and the New World*, eds. Mary Elizabeth Perry, et al. (Berkeley: UC Press, 1991), 270.

⁵² Kamen notes that, in Spain, the Inquisition was regarded as "unpleasant enough to arouse periodic protests from Spaniards" although "the scenes...conjured up by popular writers on the Inquisition have little basis in reality." Henry Kamen, *The Spanish Inquisition: A Historical Revision* (New Haven: Yale University Press, 1998), 189.

⁵³ Nesvig, *Ideology*, 191.

⁵⁴ The Mexican Inquisition was officially established in 1571 but the protection of the indigenous population from ecclesiastic and civil trials was begun by the Second Audiencia in 1530s. The Second Audiencia created a parallel civil legal system, which met directly with the viceroy, or his

related to illicit book ownership between 1571 and 1820, the books questioned were often Protestant religious works or occult works on dark magic.⁵⁵ The accused, men from the upper strata of the clergy, navy, or business world were between 33 and 38 years old and were mostly born in Spain.⁵⁶

While the Mexican Inquisition did require the semi-regular production of book inventories, particularly from printers and booksellers, it was more interested in unorthodox theological ideas than in scientific books.⁵⁷ Heretical ideas did occasionally circulate in discussions of astrology and cosmology but scientific publications typically focused on specific problems and questions. And, after the mid-seventeenth century, scientific publications in New Spain cited the use of scientific instruments to demonstrate their accuracy. For the most part the Mexican Inquisition, made out by many historians to be the great antagonist of science in the Spanish colonies, was during the early modern period in New Spain not all that interested in reading and extirpating heresy from discussions of mining, veterinary medicine, military ballistics, or other such unprovocative texts.

Though Inquisitors focused on occult books, their identification still depended upon “the personal attitude of the censors.”⁵⁸ For example, the curious works of Athanasius Kircher, with their descriptions of mysterious machines and texts in exotic scripts, circulated with ease in the colonies. The censors in Mexico City had limited resources of time and interest to regulate the enormity of the printed reading material available in New Spain, and they relied upon colleagues in Spain and Rome to identify the major outliers among European books.⁵⁹ As for novohispanic

chosen representative, and required the presence of translators fluent in half a dozen native languages. By the 1550s after an incident wherein Juan de Zumárraga, first bishop of Mexico City, had charged an indigenous Texcoco lord, Don Carlos Ometochtzin, with ‘reverting to idolatry’, a further set of statutes were enacted to protect the newly converted natives from overly zealous clergymen.

⁵⁵ On the presence of Lutheran works, particularly unofficial vernacular bibles such as the ‘Biblia del Oso,’ (Casiodoro de la Reina’s 1569 edition), in New Spain, see Alicia Mayer, *Lutero en el paraíso: la Nueva España en el espejo del reformador alemán* (México: UNAM, 2008), 98ff.

⁵⁶ José Abel Ramos Soriano, *Los delincuentes de papel: Inquisición y libros en la Nueva España, 1571-1820* (México: INAH, 2011), 275.

⁵⁷ For a comprehensive study of the Spanish Inquisition’s fluctuating interest in scientific books during the sixteenth and seventeenth century see: José Pardo-Tomás, *Ciencia y censura: la Inquisición española y los libros científicos en los siglos XVI y XVII*, vol. 13 (Valencia: CSIC, 1991), 16ff.

⁵⁸ Ávalos, “Astrology,” 99.

⁵⁹ Greenleaf suggests that readers in New Spain experienced greater freedom than in other parts of the empire: “Studies on colonial printing in Mexico, the book trade, literary production, scientific investigation, and colonial art show that a vital intellectual atmosphere prevailed and that the intelligentsia, both clergy and colonist, read, speculated, and wrote with a degree of freedom not found in Spain during the same era. In Mexico, as in Spain, those who wished to read about the new scientific

publications, the evidence suggests that *Lunario-Prognóstico* forecasts were the local scientific works in which the Mexican Inquisition took the most interest because they claimed some knowledge about the future.⁶⁰ Rather than expurgating the texts after their publication, Inquisition censors withheld the necessary license for publication until the authors eliminated specified, objectionable text. Essentially the Inquisition practiced a heavy-handed form of editorial review.⁶¹ The popularity of *Lunario-Prognósticos* made their influence upon readers noticeable to the Mexican Inquisition and the works aroused concern when their authors ventured into judicial astrology. Some *lunario* authors, like Gabriel López de Bonilla, saw themselves as qualified astrologers who deployed mathematics and astronomy to produce horoscope-like forecasts. However, the Inquisition censors judged the forecasts useful only when they were limited to calendrical and meteorological data in the manner of an almanac; any comments about “human or divine affairs” were considered potentially dangerous to general readers who might forget the doctrine of “free will.”⁶²

ideas from abroad were allowed to do so, because none of those works ever appeared on the Index of prohibited reading.”Greenleaf, “Historiography,” 271.

⁶⁰ Tayra Lanuza Navarro and Ana Avalos, “Astrological prophecies and the Inquisition in the Iberian World” (paper presented at the The Global and the Local: The History of Science and the Cultural Integration of Europe. Proceedings of the 2nd ICESHS., Cracovia, 2006), 682. See above, chapter 4, for a discussion of *Lunario-Prognóstico* forecasts.

⁶¹ The Jesuit Order also practiced a less enforceable type of editorial critique of books published by Jesuits; Athanasius Kircher for example is known to have complied with some and ignored other suggestions for changing his manuscripts prior to their publication. Daniel Stolzenberg, “Oedipus censored: censurae of Athanasius Kircher's works in the Archivum Romanum Societatis Iesu,” *Archivum historicum Societatis Iesu* 73, no. 145 (2004): 18.

⁶² Ávalos, “Astrology,” 78.

Figure 5.5: Adrian Boot's library inventory. AGN Inquisition 12213, Vol. 383, f.10

When the Mexican Inquisition did decide to examine a book collection, the process had likely begun months before with a formal complaint filed by an individual, likely an acquaintance of the accused. Processing paperwork at the Inquisition office took at least six months, as the files would be reviewed by more than one official before any further processing took place. Next a second formal complaint would be required to push the process forward. If the officials decided that the complaints merited investigating, a series of interviews with neighbors and friends of the accused would begin. After a lengthy series of interviews wherein the speakers described themselves and their relationship to the accused, the Inquisition decided whether any evidence supported the initial and secondary complaints. The accused

would not be informed of the original complaints but would simply be asked to state anything which he believed that he or she had done wrong. In the case of collector Melchor Pérez de Soto, the Inquisition made an inventory of his extensive book collection during his imprisonment.

Melchor Pérez de Soto's Scientific Book Collection

Melchor Pérez de Soto (1606-1654), a professional architect, a navigator, and astrologer in mid-seventeenth century Mexico City, owned 1,592 books, one third of which concerned mathematics and the sciences. His collection illustrates which books, of the many available for purchase, were selected for private reference by professionals whose work required the application of mathematical theorems to solve aesthetic and engineering problems. As an architect he would have also employed optical, surveying, and measuring instruments for keeping tabs on the construction process; clues about his worklife are indicated in the titles of his scientific book collection. Pérez de Soto began his collection when as a young man he inherited his uncle's library. Later in life, when the Inquisition questioned why he paid translators to render occult texts from Latin into Castilian, he responded that he "wanted to know if the books contained dubious content." Disentangling correlation from causation in astrology/astronomy, alchemy/chemistry, and magic/medicine had a long history in Europe. Practitioners and critics attempted to sort these studies into opposing categories of "reliable" and "unreliable" or—as the Mexican Inquisition would phrase it—"useful" and "harmful."⁶³ Fortunately, we have a full inventory of Pérez de Soto's books that dates to his lifetime.⁶⁴

⁶³ A similar process of differentiation was taking place in Europe during the seventeenth century; in England, John Dee (1527-1609) and Robert Hooke (1635-1703) exemplify this shift towards controlled experimentation and debate. While engaging in organized religion and holding genuine faith in divine powers formed part of the early modern scientist's worldview, the debates about what was knowable and provable, as well as the limits of time and money, made decisions to invest in particular projects over others essential. For an analysis of the process that formed "chemistry" out of chymistry, see Principe, *Secrets*, 83ff. And for a discussion of the complexities of establishing scientific authority, "virtual witnessing" through a particular genre of documentation, and social capital at play in the early years of the Royal Society of London see Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-century England* (Chicago: University of Chicago Press, 1994), 243ff.

⁶⁴ Other significant book collections for which seventeenth-century inventories are not extant include Sigüenza y Góngora's, Sor Juana's, and the Inca Garcilaso's. While parts of his printed book collection can be extracted from the references in his *Libra Astronómica*, Sigüenza y Góngora's manuscript collection has been partially reconstructed; see, Elías Trabulse, *Los manuscritos perdidos de Sigüenza y Góngora* (México: Colmex, 1988), 21ff. Much of the criollo's collection was purchased by Lorenzo Boturini Benaduci during the eighteenth century; for the inventories see: Glass, *The Boturini Collection: Mexican Government Records and Inventories, 1742-1826*. On Sor Juana's

The son and nephew of architects, Melchor Pérez de Soto was born in 1606 in Cholula, a suburb of Puebla, and later became the chief architect designing the Mexico City Cathedral.⁶⁵ His talents and interests included judicial astrology, but he had insufficient Latin to read books concerning magic without the aid of two underpaid translators who later turned him over to the Mexican Inquisition. As the Inquisition censors were considerably less interested in mathematical and scientific treatises than doctrinal and theological works, Pérez de Soto might have been free to continue building his library had he not engaged in judicial astrology.⁶⁶ On multiple occasions Melchor made astrological charts with implications for the fortunes of his listeners. Indeed he achieved a local notoriety for his horoscopes and palmreading. After Pérez de Soto's unexpected death in 1654 at the hands of a murderous cellmate, his widow acquired the books. The objectionable works contained marginal notations penned by the Inquisitors.

In his collection of over one thousand books, nearly 500 of them related to an aspect of early modern mathematics or science.⁶⁷ These works on scientific matters included texts from printing centres across Europe, a small number of which were in English, Dutch, and German. The majority were written in Spanish or Latin and some printed in Mexico City and Lima. Texts in Portuguese, French, and Italian are also

impressively large library see Ermilio Abreu Gomez, *Sor Juana Inés de la Cruz, bibliografía y biblioteca* (México: Secretaría de Relaciones Exteriores, 1934); Trabulse, "Universo," 41-50. In 2010, Ken Ward discovered an archival document at the AGN related to the sale of Sor Juana's library; he postulates that the bishop, who pressured her to sell her private book collection and donate the money to the poor, acquired the library for his own collection. The Inca Garcilaso's excellent book collection have been reconstructed from his own historical and literary publications; see José Durand, "La biblioteca del Inca," *Nueva Revista de Filología Hispánica* 2, no. 3 (1948): 239-64. By my count the Inca Garcilaso's library included: 6 works of New World Natural History, 2 on Physics, 2 catalogues of Prohibited Books, 2 on Medicine, 2 Almanacs, 2 on Architecture, 2 Agriculture, 2 on Cosmography, 1 on Navigation, 1 on Horsemanship, 1 on Military Matters, and 2 Books of Secrets.

⁶⁵ Cholula is a suburb of Mexico City's holiday town, Puebla, with a massive Nahua pyramid at its centre. Growing up within a few blocks from an imposing indigenous structure was not wasted on the future architect of the grand Mexico City Cathedral.

⁶⁶ Martin Nesvig, "The Index of Prohibited Books in Sixteenth Century Mexico: Theological Conservatism and Adaptive Responses to Censorship," *Journal of Religious and Theological Information* 10, no. 3-4 (2011): 103ff. The censors' task was to find heresy in works on religion and sometimes in works of literature or other subjects. For the most part, works published by well-known Protestants were censored regardless of the subject area but there are notable exceptions. Likewise there were regional differences affecting which books were censored; Copernicus' *De revolutionibus* was not censored in Spain. See Goodman, *Power*, 52.

⁶⁷ The number of titles in Pérez de Soto's collection is typical for a prestigious private library in seventeenth-century Spain. It compares well with the distinguished book collection of Vincenzo de Lastanosa (1607-1681) in Huesca, see Manuel-José Pedraza Gracia, "La Biblioteca de Vincencio Juan de Lastanosa," in *Vincencio Juan de Lastanosa (1607-1681): La pasión de saber*, eds. Carmen Morte García, et al. (Huesca: Instituto de Estudios Altoaragoneses, 2007), 87-95. For an overview of the collector and his library, see the Aragonese Institute of Higher Studies' "Proyecto Lastanosa" <http://www.lastanosa.com/contenido.php?gama=1&tipocontenido=2&elemento=21>

represented. It is suggestive that Athanasius Kircher's works do not appear: perhaps Pérez de Soto considered them too digressive and baggy for his library or he lacked the clerical contacts to obtain them.⁶⁸

Among his collection of manuscripts Pérez de Soto kept texts that would have been very difficult to obtain outside of the Casa de Contratación in Seville. For example, he owned four rutters produced by sailors. These *derroteros*, or written descriptions of searoutes used by pilots and navigators, included one describing the Pacific route from "Greater China" to New Spain, one description of the 2,500km journey between the ports of Acapulco (México) and Punta de Burica (Costa Rica), a guide to the islands of New Spain and South America, and a secret, official searoute from Spain to New Spain. The cosmographers at the Casa de Contratación's naval training academy considered such documents to be of grave importance not only for the preservation of a Spanish monopoly over trade but also for the safety of its sailors and cargo during times of piracy.⁶⁹

Table 5.7: Selection of 348 works from Melchor Pérez de Soto's 1,000+ book library: Authors, Editions, and Subject Areas

1. Abenare, Abraham (Venice, 1507): Astrology
2. Abril, Pedro Simón (Alcala, 1587) : Logic
3. Acosta, Cristobal de (Burgos, 1578): New World *materia medica*
4. Acosta, José de (Seville, 1590): Natural History
5. Aedo, Diego de (Cordoba, 1612): Topography of Algiers
6. Agricola, Georgius (Basel, 1556): Metallurgy
7. Aguilar, Pedro de (Seville, 1572): Horsemanship and Equine Anatomy
8. Aguilar Gordillo, Pedro de (Mexico City, 1610): Silver Trade & Metallurgy
9. Aguilera, Juan (Salamanca, 1554): Astrolabes
10. Agustín, Miguel (Barcelona, 1617): Agriculture
11. Alaba y Viamont, Diego de (Madrid, 1590): "The new science of" Military Firearms
12. Alberti, Leandro ([Venice], 1567): Geography of the Islands of Italy
13. Alberti, Leon Battista (Florence, 1550): Architecture [two more titles by Alberti]
14. Albohazen Haly Filius, Abenragel (Venice, 1503): Judicial Astrology
15. Albumasar (Venice, n.d.): Astrology
16. Alcega, Juan de (Madrid, 1580): Practical Geometry
17. Alessio, Piemontese (Venice, 1557): Book of Secrets [one more work by this author]
18. Alfonso X (Paris, 1545): Astronomical Tables

⁶⁸ Athanasius Kircher's books were popular within the intellectual circles that Melchor Pérez de Soto frequented. See Findlen, "A Jesuit's Books," 329-64.

⁶⁹ The four manuscripts are entitled: "Derrotero de la China a la Nueva España y otras partes de la gran China," "Derrotero verdadero desde el puerto de Acapulco de la Nueva España, hasta la Punta de Burica, costa de Nicaragua," "Derrotero y señas de Tierra de las Islas de Nueva España y Tierra Firme," and "Derrotero de las Armadas y Flotas que salen de España para las Indias Occidentales." The titles are listed as "Addenda" to Melchor Pérez de Soto's book inventory in Donald Castanien, "A Seventeenth Century Mexican Library and the Inquisition " (PhD Thesis, University of Michigan, 1951), 279.

19. Alhazen (Basel, 1572): Optics
20. Amico, Giovanni Battista (Venice, 1536): Astronomy
21. Anania, Giovanni Lorenzo (Venice, 1582): Cosmography
22. Andrade, Alonso do (Madrid, 1642): Military Engineering [one more work by Andrade]
23. Anduxar, Martín de (Madrid, 1640): Geometry
24. Angelis, Alexander de (Lyon, 1615): Astrology
25. Angelus, Johannes (Augsburg, 1488): Astrolabes
26. Apianus, Petrus (Antwerp, 1584): Cosmography [four more works by Apianus]
27. Apollonius of Perga (Bologna, 1566): Conic Sections
28. Archimedes (Bologna, 1565): 'On Floating Bodies' [three more works by this author]
29. Arfe, Antonio (León, c.1539): Natural Philosophy
30. Arfe de Villafañe, Juan (Seville, 1585): Measurement for Sculpture and Architecture
31. Arge de Villafañe, Juan (Cordoba, 1572): Refining Silver and Gold
32. Argensola, Bartolomé Leonardo de (Madrid, 1609): Moluccas Islands
33. Argoli, Andrea (Padua, 1638): Astronomy and 'Tycho's Hypothesis'
34. Aristarchus of Samos (Pisa, 1572): Astronomy
35. Aristotle (Paris, 1548): Physics
36. Aristotle (Madrid, 1615): Meteors
37. Aristotle (Valencia, 1621): Natural History
38. Armenini, Giovanni Battista (Ravenna, 1587): Painting
39. Aurel, Marco (Valencia, 1552): Algebra
40. Autolycus (Roma, 1588): Astronomy
41. Avelar, Fray Andrés de (Lisbon, 1590): Chronicle of Portuguese conquests
42. Avicenna (n.d.): Medicine
43. Baranzanus, Redemptus (Paris, 1617): Astronomy
44. Barley, William (London, 1596): Arithmetic
45. Barozzi, Francesco (Venice, 1585): Astrology
46. Barrientos (Salamanca, 1574): Comets
47. Barrios, Juan de (Mexico City, 1609): Chocolate
48. Barros, Alonso de (c.1612): Military Engineering
49. Bartoli, Cosimo (Venice, 1564): Perspective and Measurement 'according to Euclid'
50. Basta, Giorgio (Brussels, 1624): Military Engineering [One more work by this author]
51. Belveder, Juan (Lima, 1597): Refining Silver
52. Benedetti, Giovanni Battista (n.l., 1553): Problems from Euclid
53. Berrio de Montalvo, Luis (Mexico City, 1649): Refining Silver with Mercury
54. Bezerra, Hernando (Mexico City, 1649): Virtues of Mercury
55. Bezerra, Jerónimo (Mexico City, 1671): Silver and Gold
56. Biancani, Giuseppe (Bologna, 1615): Aristotle's Mathematics
57. Blanchinus, Joannes (Basel, 1553): Astronomy [One more title by this author]
58. Boethius, Ancius Manlius Torquatus Severinus (Paris, 1611): Mystical Numbers
59. Bonet, Juan Pablo (Madrid, 1620): Teaching the Mute to Speak
60. Bonnatti, Guido (Venice, 1506): Astronomy
61. Bordone, Benedetto (Venice, 1532): On Islands
62. Borrel, Jean (Lyon, 1559): Logic & Arithmetic [One more title by this author]
63. Bottazzo, Giovanni (Mantua, 1547): Navigation
64. Boussuetus, Franciscus (Lyon, 1558): Marine Fish
65. Brancaccio, Lelio (Antwerp, 1610): Military Engineering
66. Bressius, Mauricius (Paris, 1581): Astronomy
67. Campano, Giovanni (Venice, 1503): Quadrature of the Circle
68. Cano y Urreta, Alonso (Madrid, 1639): Gardening
69. Cano, Tome (n.d.): Shipbuilding and Fortification
70. Cárdenas, Juan de (Mexico City, 1591): Secrets of the Indies
71. Carranza, Jerónimo de (Sanlúcar de Barrameda, 1582): Military Philosophy [one more]
72. Carrillo Lasso, Alonso (Cordoba, 1624): Mines of Spain
73. Castrillo, Hernando (Zaragoza, 1639): Magic or "Science of occult philosophy"

74. Castriotto, Jacomo Fusto (Venice, 1583): Fortifications
75. Cataneo, Girolamo (Brescia, 1571): Military Engineering [one more work by this author]
76. Cataneo, Pietro (Venice, 1567): Mathematics
77. Cavellat, Guillaume (n.d.): Cosmography
78. Cepeda, Fernando de (Mexico City, 1637): Relation on the Site of Mexico City
79. Cerdán, Pablo (Tortosa, 1624): Arithmetic
80. Cerone de Bergamo, Pedro (Naples, 1613): Music Theory and Practice
81. Cervantes de Salazar, Francisco (Mexico City, 1560): History of Mexico City
82. Champier, Symphorienm (n.d.): Medicine
83. Chavez, Jerónimo de (Sevilla, 1566): Repertory of Current Events & Ephemerides
84. Ciruelo, Pedro (Alcalá, 1521): Astrology [three more works by this author]
85. Cisneros, Diego (Mexico City, 1618): Prognostications
86. Clavius, Christopher (c.1580): Practical Geometry
87. Clowes, William (London, 1591): Surgery for Gunshot Wounds
88. Coelho de Barbuda, Luis (Lisbon, 1624): Military Deeds
89. Collado, Luis (Milan, 1592): Arms and Military Engineering
90. Conietto, Miguel (n.d.): Geometry of Pantometers
91. Crescentio Romano, Bartolomeo (Rome, 1607): Nautical charts
92. Danti, Egnazio (Florence, 1578): Making Astrolabes and Planispheres
93. Dariotus, Claudius (Lyon, 1557): Introduction to Astronomy
94. Commandinus, Fredericus (Bologna, 1565): Mathematics of a Centre of Gravity in Solids
95. Copernicus, Nicolaus (Basel, 1566): On the Revolutions of the Celestial Spheres
96. Correa, Juan (Mexico City 1648): Discourse on an Anatomical Dissection in Mexico City
97. Cortés, Jerónimo (Valencia, 1594): Refining Coins
98. Cortés, Jerónimo (Madrid, 1598): Secrets of Nature
99. Cortés, Jerónimo (Valencia, 1594): Prognostications [one more work by this author]
100. Cortés, Martín (Sevilla, 1551): Art of Navigation
101. Daza, Esteban (Cordoba, 1575): Music
102. Del Canto, Francisco (n.d.): Agriculture
103. De Gante, Ambrosio (n.l., 1580): Astronomy
104. De Mesa, Diego Pérez (n.d.): Making and using Astrolabes
105. Descrittione, et uso dell'holometro (Venice, 1564): Instrument of Measurement
106. Diaz de Viena, Luis (Barcelona, 1639): Military Engineering
107. Diez, Manuel (Zaragoza, 1495): Horseback Riding, Training, and Animal Health
108. Diez Daza, Alonso (Sevilla, 1576): Dangers and Benefits of Drinking Water
109. Dioscorides, Pedacius (Antwerp, 1555): Medicine
110. Durer, Albrecht (Venice, 1591): Symmetry of the Human Form
111. Echagoyan, Felipe (México, 1630): Tables of Coin Equivalences
112. Eguiluz, Martín de (Madrid, 1592): Military Discipline
113. Escalante, Bernardino de (Sevilla, 1583): Military Discipline [one more work]
114. Espinosa, Pedro de (Cadiz, 1625): Veterinary Medicine
115. Euclid (Antwerp, 1645): Geometry [eight more works by this author]
116. Farfán, Agustín (México, 1579): Medicine
117. Fernández, Diego (Seville, 1571): Events in Peru and México
118. Fernández, Francisco (Madrid, 1579): Comets
119. Fernández de Andrada, Pedro (Seville, 1599): Spanish Horseback Riding [two more]
120. Fernández de Enciso, Martín (Seville, 1519): Geography of the World
121. Fernández de Eyzaguirre, Sebastián (Brussels, 1608): Arithmetic
122. Ferrero Maldonado, Lorenzo (Alcalá, 1626): Cosmography of the Globe
123. Figueiredo, Manoel de (Lisbon, 1625): Hydrography for Pilots with Rutters
124. Finaeus, Orontius (Paris, 1556): Mathematics of Circular Quadrature [one more work]
125. Fioravanti, Leonardo (Venice, 1571): Secrets of Medicine, Surgery, and Alchemy
126. Fioravanti, Leonardo (Venice, 1567): Mirror of Universal Science
127. Firmicus Maternus, Julius (n.d.): Astrology
128. Firrufino, Julio César (Madrid, 1626): On Artillery

129. Flurance Rivault, David de (Paris, 1608): Elements of Artillery
130. Freire de Sylva, Luis (Barcelona, 1638): Astronomical “Ephemerides”
131. Fuentes, Alonso de (Seville, 1547): Astrology and Astronomy
132. Gallo, Agostino (Turin, 1579): Agriculture
133. Gallo, Antonio (Madrid, 1639): On Military Engineering
134. Gallucio, Juan Pablo (Granada, 1614): On Measuring Longitude and Latitude
135. García de Cespedes, Fray Andrés (Madrid, 1606): Instruments for Geometry and Surveying [one more title by this author]
136. García de Palacio, Diego (Mexico City, 1583): Military Engineering
137. García de Palacio, Diego (México, 1587): Navigation and shipbuilding
138. Gaspar, Nicolás (Lisbon, 1677): Arithmetic
139. Guarico, Lucas (c. 1550): Geometry
140. Gesner, Conrad (Tiguri, 1551): Natural History
141. Gilbert, William (London, 1600): Magnets
142. Giovio, Paolo (Venice, 1608): Military Arms [one more work]
143. Giuntini, Francesco (Cologne, 1580): Astrological divination [one more work]
144. Geber ben Aphla (Norimberg, 1534): Astronomy
145. Gemma, Cornelius (Antwerp, 1569): ‘Cyclognomic arts’
146. Gemma Frisius (Antwerp, 1540): Practical arithmetic
147. Gemma Frisius (Antwerp 1553): Principles of Astronomy and Cosmography [one more]
148. González de Medina Barba, Diego (Madrid, 1599): Military Fortifications
149. González de Mendoza, Juan (Madrid 1580): Kingdom of China
150. Gracián de Alderete, Diego (Barcinone, 1566): Military Matters
151. Granado, Cristobal (Seville, 1618): Flebotomy
152. Grisón, Federico (Baeza, 1568): Nature of Horses
153. Guevara, Pedro de (Madrid, 1586): Raymund Lull’s Art of all Sciences
154. Gutiérrez de Gualba, Juan (Toledo, 1539): Arithmetic
155. Havemann, Michael (Rostochii, 1624): Astronomy
156. Hemminga, Sixtus ab. (Antwerp, 1583): Astrology
157. Hera, Pedro de la (Madrid, 1584): Cosmography
158. Hernández, Francisco (Mexico City, 1615): Ximénez’s selection from Hernández’s Natural History
159. Hernández de Oviedo y Valdés (Sevilla, 1535): Natural History of the Indies
160. Hero of Alexander (Venice, 1572): Military Machinery and Artillery [one more work]
161. Herrera, Antonio de (Madrid, 1589): Scotland and England under Mary Stuart [four more works by this author]
162. Isla, Lázaro de la (Madrid, 1595): Geometric Arts of Artillery and Firearms
163. Izabá, Marcos de (Madrid, 1594): Military Recommendations
164. Kepler, Johannes (Lentus ab Danubium, 1618): Copernican Astronomy
165. Lavanha, Joao Baptista (Lisbon, 1595): Military Navigation
166. Lechuga, Cristobal (Milan, 1603): Military Exercises
167. Herrera, Gabriel Alonso de (Madrid, 1620): Agriculture
168. Herrero, Simón (Barcelona, 1626): Secrets of Nature
169. Hidalgo de Agüero, Bartolomé (Valencia, 1654): Surgery
170. Huarte de San Juan, Juan (Baeza, 1575): Examination of Talents for the Sciences
171. Iciar, Juan de (Zaragoza, 1559): Subtle instruction for perfect writing and counting
172. López de Bonilla, Gabriel (Mexico City, 1653): The Comet of December 1653
173. López de Corella, Alonso (Zaragoza, 1507): Medical Astrology
174. López de Hinojosa, Alonso (Mexico City, 1578): Surgery
175. López de Sigura, Ruy (Alcalá, 1561): Playing Chess
176. León, Fray Andrés de (Baeza, 1590): Anatomy
177. Longomontanus, Christianus Severinus (Amsterdam, 1622): Astronomy
178. López de Arenas, Diego (Seville, 1633): Carpentry according to Nicolas Tartaglia
179. Lull, Ramón (Nuremberg, 1546): Alchemy
180. Lull, Ramón (Barcelona, 1565): Encyclopedia of the Arts

181. Magini, Giovanni Antonio (Venice, 1582): Astronomical Ephemerides [two more works]
182. Manzanar, Eugenio (Toledo, 1570): Horseback riding
183. Marincola, Domenico (Naples, 1637): Military Engineering
184. Marolois, Samuel (Amsterdam, 1651): Fortifications and Military Architecture
185. Martínez, Enrico (Mexico City, 1606): Natural History of New Spain
186. Martínez, Juan (Alcalá, 1532): Music and the Art of Song
187. Martínez Motiño, Francisco (Madrid, 1611): Art of Cookery
188. Martínez Población, Juan (Paris, 1527): On Using Astrolabes
189. Martinus Siliceo, Joannis (1526): Arithmetic
190. Maurolycus, Franciscus (Venice, 1543): Cosmography and Astronomy [three more]
191. Medina, Pedro de (Cordoba, 1545): Art of Navigation [two more works]
192. Mela, Pomponio (Madrid, 1642): Geography
193. Meli, Micaelis (n.d.): Arithmetic, Music, and Geometry
194. Melzo, Ludovico (Antwerp, 1611): Military regulation
195. Mendes de Vasconcelos, Luis (Lisbon, 1612): Arts of the Military
196. Mendoza, Bernardino (Madrid, 1595): Theory and Practice of War [one more work]
197. Mercado (Madrid, 1599): Medical Anatomy and how to set Bones
198. Merola, Jerónimo (Barcelona, 1588): The Human Body
199. Mesa, Sebastián de (Barcelona, 1630): Journey in Africa
200. Michelis Márquez, José (Madrid, 1642): Military Horseback
201. Minadoy, Juan Tomás (Madrid, 1588): War of Turks and Persians
202. Mizaldus, Antonius Monslucianus (Paris, 1554): Astrological Ephemerides [one more]
203. Moerman, Jan. (Antwerp, n.d.): Of Creatures
204. Moletius, Jos. (Venice, 1563): Astronomical Ephemerides
205. Monantheuil, Henri (c.1600): Art of Mechanics
206. Monardes, Nicolás (Sevilla, 1574): Materia Medica
207. Montanos, Francisco de (Salamanca, 1610): Music [one more work by this author]
208. Montebrunus, Franciscus (Bologna, 1640): Astronomical Ephemerides
209. Montemayor, Cristobal de (Valladolid, 1613): Medicine and Surgery
210. Moreno, Cristóbal (Barcelona, 1596): Simples (Medicinal Recipes)
211. Mosquera de Figueroa, Cristóbal (Madrid, 1596): Military Discipline
212. Nabod, Valentin (Cologne, 1560): Astrology
213. Nájera, Antonio de (Lisbon, 1628): Navigation
214. Nájera, Antonio de (Lisbon, 1632): Astrology
215. Nautonnier, Guillaume de (Venice, 1603): Measuring Longitude
216. Nicolay, Nicolas de (Antwerp, 1576): Navigation and a voyage in Turkey
217. Nieremberg, Juan Eusebio (Alcalá, 1649): Curious and Occult Philosophy [four more]
218. Nodal, Bartolomé García de (Madrid, 1621): Voyage through Magellan's Strait
219. Nola, Roberto de (Toledo, 1525): Book of Cookery by the viceroy of Naples' chef
220. Nostradamus, Michel (Lyon, 1555): Prophecies
221. Nuñez, Francisco (Alcalá, 1580): Secrets of Human Births
222. Nuñez, Pedro (Antwerp, 1567): Algebra, Arithmetic, and Geometry
223. Nuñez, Pedro (Coimbra, 1573): Art and Reason of Navigation
224. Nuñez, Pedro (Lisbon, 1537): Treatise of the Sphere
225. Nuñez de Coria, Francisco (Madrid, 1572): Good health according to doctors [one more]
226. Nuñez de Zamora, Antonio (Salamanca, 1610): Book of Comets
227. Obregón y Cerezeda, Antonio de (Valladolid, 1603): Aristotle's Philosophy
228. Oliveira, Simón de (Lisbon, 1606): Art of Navigation
229. Origanus, David (Froft., 1609): Brandenburg Ephemerides
230. Ortega, Juan de (Cadiz, 1624): Naval Astronomy; Moon and Tides
231. Ortega, Juan de (Sevilla, 1552): Most subtle Arithmetic and Geometry [one more work]
232. Ortelius, Abraham (Antwerp, 1596): Geography
233. Otañez de Escalante, Diego de (Alcalá, 1584): Repertory of the times
234. Osorio de la Pena, Diego (n.d.): Military engineering

235. Ovalle, Alonso de (Rome, 1646): Jesuit Missions in Chile
236. Pacheco, Francisco (Sevilla, 1649): Art of Painting
237. Pacheco de Narvaez, Luis (Madrid, 1635): Skill in Arms [one more work]
238. Pagani, Francesco (Ferrara, 1591): Arithmetic
239. Palladio, Andrea (Venice, 1570): Four Books of Architecture [one more work]
240. Pantheus, Joannes Augustinus (Paris, 1550): Art and Theory of Metallurgy
241. Pappus of Alexandria (n.l., 1588): Mathematics
242. Paracelsus (Paris, 1567): Philosophy and Medicine
243. Paracuellos, Miguel de (Zaragoza, 1658): Caring for Horses
244. Pasino, Aurelio de (Antwerp, 1579): Military Engineering
245. Paz, Pedro (Mexico City, 1623): Art of Arithmetic
246. Pérez de Bustos, Diego (Madrid, 1641): Flebotomy
247. Pérez de Mesa, Diego (n.d.): Judicial Astrology
248. Pérez de Moya, Juan (Alcala, 1582): Arithmetic [five more works by this author]
249. Pérez de Portillo, Luis (Pinciae, 1568): The Khan and Horses
250. Pérez de Vargas, Bernardo (Toledo, 1593): Astrology
251. Pérez de Vargas, Bernardo (Madrid, 1569): Secrets of Metallurgy
252. Pérez de Xea, Miguel (Madrid, 1632): Military Arts
253. Peverone, Giovanni Francesco (Lyons, 1558): Arithmetic and Geometry
254. Philander, Gulielmus (Paris, 1545): Architecture
255. Piccolomini, Alessandro (Rome, 1582): Aristotle's Mechanics [three more works]
256. Pitatus, Petrus (Tubingen, 1553): Astronomy
257. Pitici, Bartolomei (n.d.): Geometry
258. Plinius Secundus, Caius (Madrid, 1624): Natural History
259. Porcacchi da Castiglione, Tomaso (Venice, 1576): The World's most famous Islands
260. Porta, Giambattista della (Naples, 1588): Natural History [two more]
261. Porter y Casanate, Pedro (Zaragoza, 1634): Navigation
262. Poza, Fray Andrés de (Bibao, 1585): Curious Hydrography
263. Proclus Lycius (Florence, 1573): Cosmography
264. Ptolemaeus, Claudius (Venice, 1519): Astronomy
265. Ptolemaeus, Claudius (Venice, 1558): On the Planisphere
266. Purbachius, Georgius (Paris, 1558): New theory of the Planets
267. Rades y Andrada, Francisco de (Toledo, 1572): Equestrian Arts
268. Ramírez, Baltasar Francisco (Madrid, 1629): Horsemanship
269. Ramírez de Carrión, Manuel (Cordoba, 1629): Marvels of Nature
270. Ranzovius, Henricus (Frankfurt, 1602): Astrology
271. Reatón Pasamonte, Atanasio (Mexico City, 1649): Art of Arithmetic
272. Regiomontanus, Johan Muller (c. 1460): Astronomy [one more work by this author]
273. Reinhold, Erasmus (Tubingen, 1551): Astronomy
274. Reyna, Francisco de la (Alcalá, 1623): Book of Horsemanship
275. Rio, Martín del (Lyons, 1608): Magic
276. Río, Gregorio de los (Madrid, 1592): Agriculture and Gardens
277. Rivas, Pedro de (Madrid, 1581): Preservation of Good Health [one other work]
278. Riviera, Cesare della (Milan, 1605): Magic
279. Rocamora y Torrano, Ginés (Madrid, 1599): Sphere of the Universe
280. Rocha, Antich. (Barcelona, 1564): Arithmetic
281. Rocha, Francisco de la (Valencia, 1618): Geometry
282. Rodríguez, Antonio (Salamanca, 1596): Accountancy and tables for trading currencies
283. Rojas, Cristóbal de (Madrid, 1613): Fortifications [one more work by this author]
284. Romano, Bartolomeo (Naples, 1595): Military Arts
285. Romano de Córdoba, Alonso (Madrid, 1617): Surgery
286. Ruiz, Pedro (Valencia, 1575): Solar Clocks
287. Rusconi, Giovanni Antonio (Venice, 1590): Architecture
288. Saavedro, Valentino de (Lisbon, 1620): Navigation
289. Sabuco, Oliva (Madrid, 1587): Philosophy of Man for Good Health

290. Sacro Bosco, Johannes de (Venice, 1499): Cosmology [seven more works by this author]
291. Sagredo, Diego de (Toledo, 1549): Vitruvian measurements
292. Salero, Francisco (n.d.): Navigation and cosmography
293. Saldias, Pedro (Sevilla, 1637): Tables for Refining Silver
294. Saminiati, Federicus (Antwerp, 1599): Astronomical Tables
295. Santa Cruz, Miguel Gerónimo de (Sevilla, 1603): Speculative and Practical Arithmetic
296. Santiago, Diego de (Sevilla, 1598): Medicines
297. Sarabia de la Calle Veronense (Medina, 1544): Instructions for Merchants
298. Savanarola, Miguel (Sevilla, 1541): Regimen for Health
299. Scarion de Pavía, Bartolomé (Lisbon, 1598): Military doctrine
300. Schoner, Andreas (Norinburg, 1561): Gnomons
301. Sempilius, Hugo (Antwerp, 1635): Discipline of Mathematics
302. Serlio, Sebastiano (Venice, 1551): Architecture [one more work]
303. Serrano de Biedma, Cristóbal (Sevilla, 1619): Geometry
304. Silva y Olivera, Francisco de (Granada, 1603): Curing contagions
305. Siria, Pedro de (Valencia, 1602): Navigation
306. Sirigatti, Lorenzo (Venice, 1596): Perspective
307. Solino, Julio (Sevilla, 1573): Marvels of the World
308. Sorapán de Rieros, Juan (Granada, 1616): Medicine
309. Stadius, Joannes (Cologne, 1570): Astronomical Ephemerides [one more work]
310. Stevin, Simon (Rotterdam, 1617): Fortifications [one more work by this author]
311. Stoffler, Joannes (Oppenheim, 1512): Astrolabes
312. Suárez de Argüello, Francisco (Madrid, 1608): Astronomical Ephemerides
313. Suárez de Figueroa, Cristóbal (Madrid, 1613): Universal Sciences and Arts [two more]
314. Suárez de Peralta, Juan (Sevilla, 1580): Horsemanship [one more work]
315. Tagliente, Giovanni Antonio (Venice, 1611): Book of the Abacus
316. Tamayo, Fray Andrés de (Madrid, 1621): Treatise on Algebra
317. Tariffa generale per pesi e misure de Asia, Africa (Genoa, n.d.): Tables of measurement
318. Tartaglia, Niccolo (Venecia, 1606): Treatise on Numbers [one more work by this author]
319. Theophrastus (Tarvisii, 1483): Natural History of Plants
320. Theti, Carlo (Rome, 1559): Fortifications
321. Tornamira, Francisco Vicente de (Pamplona, 1585): Cosmography and Astronomical Computations [one more work by this author]
322. Torquemada, Antonio de (Salamanca, 1570): Curious Flowers and Geography
323. Tovar, Simón de (Sevilla, 1595): Using the Ballestilla to measure the North Star
324. Ubaldi, Guido (Pisa, 1577): Book on Mechanics
325. Ufano, Diego (Brussels, 1613): Treatise on Artillery
326. Valdés, Francisco de (Madrid, 1591): Military Discourse
327. Valle, Battista della (Venice, 1550): Fortifications and Artillery
328. Vallés, Francisco de (Madrid, 1592): Treatise for pharmacists on distilling and measuring fluids
329. Valturius, Robertus (n.l.,1472): Medical surgery and military matters
330. Vargas Machuca, Bernardo de (Madrid, 1621): Horsemanship [two more works]
331. Vázquez de Espinosa, Antonio (Malaga, 1623): Voyage of the New Spain and Honduras Fleet
332. Vázquez de Serna, Juan (Cadiz, 1620): Tables for refining gold
333. Vegetius Renatus, Flavius (Paris, 1532): Military matters
334. Vélez de Arciniega, Francisco (Madrid, 1613): Veterinary medicine [one more work]
335. Veronese, David (Genoa, 1627): Mercantile arithmetic
336. Vidijs, Vidus (Paris, 1544): Surgery
337. Vignola, Jacome de (Madrid, n.d.): Five orders of architecture
338. Villa, Estebán de (Burgos, 1637): On plants
339. Ville, Antoine de (Lyon, 1640): Fortifications

340. Villegas, Sebastián Vicente (Seville, 1604): Music
 341. Vitellionis (n.d.): Mathematics
 342. Vitruvius Pollio, Marcus (Lyons, 1586): Architecture [two more titles by this author]
 343. Vecker, Hans Jacob (Basel, 1604): Book of Secrets
 344. Voellus, Joannes (Tournon-sur-Rhône, 1608): On clockmaking
 345. Xamarro, Juan Bautista (Madrid, 1604): Care of caged birds
 346. Zamorano, Rodrigo (Seville, 1581): Art of Navigation
 347. Zaragozano, Victoriano (Logroño, 1594): Almanac
 348. Zarlino, Gioseffo (Venice, 1574): Harmonic demonstrations [one more title]
- The inventory includes an additional 87 works, similar to these, but without authors.

Source: Selected from "Secular Non-Fiction" in Donald G. Castanien *A seventeenth century Mexican library and the inquisition* 1951.

The Mexican Inquisition's inventory of Pérez de Soto's specialist library reveals the breadth and eccentricity of someone who sought rare books for the pleasures of collecting and for furthering his own professional expertise.⁷⁰ Though the archival documents do not mention the instruments Melchor used for his work, one could surmise that he owned, and may have built, some of the tools mentioned in the titles to his technical manuals, such as the cross-staff and different types of clocks. My selection from Castanien's transcription includes the histories and chronicles which indicated in their titles discussions of astronomical ephemerides or descriptions of geography and topography. Of the 348 titles listed above, 17% discuss Astronomy/Astrology, 7% Navigation, 20% Architecture and Engineering, 17% Mathematics and Measurement, 10% Natural History or Plants and Animals, 11% Medicine and Anatomy, 4% Metallurgy, 4% Geography and Topography, and 9% Other.⁷¹ Pérez de Soto's library portrays a Mexico City with well-stocked libraries and avid readers.

⁷⁰ I have compared Donald Castanien's transcription of the archival documents with the AGN's published transcription of the Inquisition inventory and found that Castanien identified many of the titles and authors which were deemed incomplete or illegible in the AGN transcription. Castanien's dissertation offers an introduction to New Spain as a political entity and then presents a complete list of Pérez de Soto's books; he does not discuss the scientific works or identify them. I have selected, translated, and abbreviated the above titles from Castanien. See Inquisition, "Una biblioteca del siglo XVII," in *Documentos para la Historia de la Cultura en Mexico, Archivo General de la Nación* (México: Imprenta Universitaria, 1654 (1947)), 3-94; Castanien, "Mexican Library," 153-289.

The John Carter Brown exhibition "Melchor Pérez de Soto: A book collector faces the Inquisition" http://www.brown.edu/Facilities/John_Carter_Brown_Library/exhibitions/perez/perezindex1.html displays 30 of the scientific titles from Pérez de Soto's inventory.

⁷¹ "Other" includes works on Optics, Secrets, Hydraulics, Music, Universal Sciences, Natural Philosophy, Magnets.

Conclusion: The Circulation of Scientific Knowledge in New Spain

During the sixteenth and early seventeenth centuries the Casa de Contratación preserved much of Spain's empirical science as *arcana imperii* (state secrets) for the Council of Indies. Nevertheless, published books recording Spain's scientific contributions were widely available and frequently translated into other European languages.⁷² Support for these information gathering endeavours slowed as the novelty of the Americas declined and Philip II's successors focused on tackling runaway inflation. In the second half of the seventeenth century, a comparative disinterest in science resulted in the reduction of state-funding for it. Scholars concur that in 1675-1700 Iberian science diverged from that produced elsewhere in Europe. Though 'imperial science' diminished, colonial science continued to produce new astronomical and cartographic observations, and colonial scientists established epistolary ties to practitioners in Europe and Asia.⁷³

The decline of state-funded science in Spain provides a backdrop to explain why the Society of Jesus sought scientific observations made in the colonies and shared results via their transoceanic networks. European museum collections and royal botanic gardens of the seventeenth century included an array of artwork and botanic specimens from the Spanish Americas.⁷⁴ These collections across early modern Europe demonstrate that curiosity about American cultural artifacts and

⁷² Barrera-Osorio has noted the influential translations of Spanish navigation manuals into English. Barrera writes: "In 1545, Pedro de Medina published the *Arte de navegar*, which was translated into Italian (three editions by 1609), French (15 editions by 1633), Dutch (five editions by 1598), and English (two editions in 1581 and 1595)" He highlights Cortés' *Breve compendio de la sphaera y de la arte de navegar* (1551) which became "the foundational text for England's long tradition of sea-dominance and colonization" under Stephen Borough's direction of the English Muscovy Company. Boroughs had purchased a copy of the *Breve Compendio* during his visit to the Casa de Contratación in Seville. Richard Eden's translation rendered it the *Art of Navigation* in 1561 and it was reedited six more times in London before 1600. Barrera-Osorio points out that "pirates Martín Frobisher and Francis Drake were among the Englishmen who enjoyed and used Cortés's book." (For more pirates' personal book collections, see Clayton McCarl, "Ghost Journeys and Phantom Books: Francisco de Seyxas y Lovera's Elusive Library of Pirates," *Book History* 17, no. 1 (2014): 165-90.) And the work appears to have influenced theories of magnetism in Robert Norman's *The Newe Atractive* (1581) and William Gilbert's *De magnete* (1600) treatises. See, Folger Institute blog post by Antonio Barrera "Navigational Manual of Cortés." http://www.folger.edu/html/folger_institute/experience/disciplining_barrera.htm

During the same era, a work of *materia medica*, Monardes' *Historia medicinal* was translated by John Frampton as *Joyfull News out of the New Found World* in 1577.

⁷³ In the *Libra*, Sigüenza y Góngora lists his epistolary contacts as including astronomers and mathematicians in Florence, Bologna, Paris, London, Madrid, and Seville.

⁷⁴ Rafael Chabrán, "Dr. Francisco Hernández and Denmark: The Presence of *The Mexican Treasury* in the Work of Ole Worm." *The Colorado Review of Hispanic Studies* Vol. 7, Fall 2009 pages 169–183.

materia medica was not only fashionable but fed into what historians call the “New Science” as it developed.

After Philip II’s death in 1598, the locus of scientific production and patronage shifted from the monarchy to the increasingly powerful Jesuit Order both within Spain and the Americas.⁷⁵ Likewise the eyes of European scientists and intellectuals gradually lost interest in Spain’s scientific books and turned toward their own empirical projects. The now standard view of Spain’s intellectual isolation during the seventeenth century ignores the applied nature and local geography of scientific thinking at work within as well as across the Spanish territories. The book inventories discussed in this chapter suggest that by the end of the seventeenth century Spain’s intellectual communities in Mexico City had become a centre for the communication of science in the Americas: the locus of scientific practice had shifted westward towards the geographic centre of the empire—New Spain.

⁷⁵ Navarro Brotóns, "Tradition," 331ff. That is, until their expulsion—from Spain and its territories—in 1767 under the Bourbon Monarchy.

Conclusion

Historians have studied scientific innovation throughout the Atlantic World, but comparatively little is known about how scientists worked and thought in New Spain. Though shipping records only partially document the movement of books from Europe to the Spanish empire, this thesis investigated Inquisition records and discussed several New World scientists to follow the circulation of their works throughout the Spanish Empire and Europe. The thesis also revealed that Mexican libraries held a wealth of ideas about machines and the mathematical approach to science. The urban aristocratic culture of Mexico City favoured scientific travellers as they glided between roles as cultural brokers with royal or religious appointments within global networks of idea, text, and scientific instrument exchange.

I have argued here that Mexico City was a hub of scientific knowledge production through the year 1700 in the Americas.¹ Diego Rodríguez's reliance upon mathematics in the first half of the seventeenth century and Sigüenza y Góngora's visions of empiricism during the last quarter of the same century are representative of the main forms of scientific thought and practice in the New World. Until the explicit introduction of the Spanish naturalists' methods after 1760 New Spain scientists and Jesuit missionaries used the tools of the late seventeenth century.² By viewing Mexico

¹ In 1929 Leonard asserted: "During the seventeenth and eighteenth centuries the City of Mexico was, in reality, the metropolis of the western hemisphere... The Royal University of México was at this time a flourishing institution... These learned gentlemen made real contributions to knowledge of which contemporary and later European scientists and scholars were glad to avail themselves." Leonard, *Mexican Savant*, Preface, ix. A related point by Brazilian professor of mathematics, who when outlining the History of Mathematics in Latin America writes: "It is imperative to mention the developments in Nueva España in this [colonial] period. Most of the developments in Central and South America are dependent on the important and strategic position of Mexico in the New World," Ubiratan D'Ambrosio, "Mathematics in South and Central America," in *Using History to Teach Mathematics: An International Perspective*, ed. Victor Katz (Cambridge: Cambridge University Press, 2000), 247.

² Jesuit book inventories produced in New Spain upon the expulsion of the Society of Jesus from all Spanish territories in 1767 show that book collecting from overseas slowed down after 1680 despite the increased number of Jesuit missions during the eighteenth century. See Trabulse, *Ciencia y tecnología*, 37-43. By the last quarter of the eighteenth century new tools and procedures were used by novohispanic scientists for calculating longitude but the period from the middle of Charles II's reign 1690 through to the six royal botanical expeditions (1760-1803) had coincided with major developments in scientific practice within Europe. José Antonio Alzate (1737-1799), a notable

City as a hub of scientific activity, we present a more complete picture of New Spain, have a better sense of its role as funder and participant in the scientific revolutions in Europe, and see how the foundational period of Spanish Colonial Science produced new knowledge.

Historians of science have debated when and how “science” acquired the accoutrements of a technologically dependent, testable process of systematic investigation. Newton and Leibnitz’s work on calculus for describing the trajectory of comets as well as Newton’s work in optics and advances with telescopes set the stage for a different kind of eighteenth century science. More sophisticated tools for describing the natural world became available primarily within Europe, which took root in the Spanish colonies more gradually after the seventeenth century. A conceptual shift towards the mathematisation and mechanisation of nature took hold and crystalized during the long eighteenth century, as seen through the productive and sometimes fierce competition between the Royal Society of London and the Académie des Sciences in Paris.

By contrast, early modern science in New Spain was based on observations, first-hand experiences recorded and synthesized in the form of reports often with an eye towards publication. The “outdoor” aspects of botanical, astronomical, and engineering observations in New World science are significant in that they differ from precisely the kinds of indoor experiments that the Royal Society of London made famous with figures like Newton, Boyle, and Hooke. Novohispanic science also included some indoor observations, such as the anatomical dissections performed before an audience of medical students and physicians in Mexico City, but this thesis has focused on scientific activities which observed or contended with the natural environment.³

New World science thus was experiential, descriptive, and analytical, and scientists there sought to publish their work. First-hand accounts of comets, islands, and indigenous practices featured in numerous manuscripts and imprints. The Crown or viceroy, religious orders or private patrons financed printed work, which typically led to future commercial opportunities. New World science thrived though it was at times limited by religious or legal prohibitions, and sometimes by distance from Old

novohispanic polymath, produced during the final quarter of the eighteenth century, maps of New Spain that finally exceeded the cartographic accuracy of Sigüenza y Góngora’s a century earlier.

³ Miruna Achim, “Fractured Visions: Theaters of Science in Seventeenth-century Mexico” (PhD Thesis, Yale University, 1999), 25ff.

World production centres of specialized tools. Scientific activity required time off from other productive activities, resources to support outdoor observation with an indoor writing space, and the support or competitive urgings of peers.⁴ Figures like Sigüenza y Góngora serve to remind us that, despite the distance and ocean crossing, some Mexico City scientists succeeded at maintaining collegial relationships with mathematicians in Europe via correspondence.⁵ Between 1554 and 1700 Mexico City printers published more than 118 works on mathematics while printers in the only other major viceregal capital in the Americas during this period, Lima, produced forty-one.⁶

But if Mexico City had the best array of financial, institutional, and intellectual resources in the Americas during the era of the Habsburg viceroys, then why did it not produce an Academy of Science and figures whose mechanical innovations are still celebrated today? While the Inquisition promoted a mathematical seriousness of thought about astronomy, linguistics, cartography, and other analytic-descriptive forms of knowledge production, it hindered the free range of heterodox thinking—including astrological and magical-alchemical experimentation—which inspired other major figures such as Kepler and Newton. Distance from colleagues willing to collaborate in the many, competitive, tightly connected courts of Europe lessened the novohispanic scientist's creativity of experimentation.⁷ The conditions

⁴ The outdoor observations and measurements certainly included a basic indoor reporting component as well. On how to sketch a property map "later that evening" after surveying land: "Once the perimeter of a plot of land is measured, later, at home upon a table and large sheet of paper with the use of a map scale, the surveyor can draw a map representing the land measured that day." Biblioteca Nacional de México, "José Saénz de Escobar. Geometría práctica y mecánica. Tratado primero: De medidas de tierras, 1736," (Fondo Reservado, Manuscritos, Signatura 1528, fol.128).

⁵ The role of the Spanish postal service cannot be ignored in these instances (see above, Chapter 2 note 50); despite his status as a "secular" priest—Sigüenza was not affiliated or supported by any particular religious order—he established communications with the Jesuit José Zaragoza. Without relying on the Spanish post, religious orders managed long-distance communication with relative efficiency; see, J. Martínez-Serna, "Procurators and the Making of the Jesuits' Atlantic," in *Soundings in Atlantic History. Latent Structures and Intellectual Currents, 1500-1830*, eds. Bernard Bailyn, et al. (Cambridge: Harvard University Press, 2009), 181ff.

⁶ Burdick notes that his bibliography has likely undercounted the number of Mexican almanacs produced before the year 1700 whereas he is more certain about his figures for other printing centres in the Americas, see Burdick, *Mathematical Works*, 9-17; 17.

⁷ Anatomical dissection in Mexico City, for example, was modest in its aims; it sought to diagnose the cause of death and promote a visual understanding of the human body. The dissections were performed within a religious conception of the Second Coming when human bodies would be rejoined to the souls of the dead. See: Achim, "Fractured Visions," 40. Vivisection as it was practiced at the Royal Academy of Science in London was less concerned with keeping human bodies sacrosanct or animals from suffering, and hence it was much freer to try, fail, and try again without too much worrying over the potential death of a mouse, dog, or drunkard. For a vivid discussion of the Royal Society's experiments and activities see Lisa Jardine, *Ingenious Pursuits: Building the Scientific Revolution* (London: Abacus, 1999), 52.

which inspired Galileo to design the telescope from a Flemish spying toy did not exist in the less compact American landscape.⁸

Until recently, the historiographical focus upon inventions, discoveries, and developments in the physical sciences has obscured our view of how seventeenth-century scientists studied the natural world. Spanish and novohispanic botanists, hydraulic engineers, and astronomers exchanged tools and techniques with explorers, ethnographers, linguists, native historians, and poet-clergymen to produce new forms of knowledge. New Spain's men of science, a sizeable portion of whom were clergymen trained in mathematics, turned their attention to addressing immediate questions and concerns of relevance to local conditions. If they did not innovate to the extent of scientists in Europe, they did argue for significant ideas about the validity of mathematics over prognostication, the value of human lives over financial gain, and the virtues of recording indigenous knowledge.

New Spain began as an extension of Europe in the first quarter of the sixteenth century and by the end of the Habsburg era had developed a two-ocean economy that under the Bourbon monarchy encouraged its independence from colonial rule. During this period it was productive as well as receptive in areas of applied mathematics and those areas today known as the social sciences. Mexico City was a location of scientific knowledge production by virtue of its wealth of resources: human capital, centrality of governance, finance, and communication centres. Contrary to popular belief, persons involved in scientific activities were not difficult to find in New Spain. If we take Sor Juana as representative of her religious sisters, then even lesser-known nuns may have viewed cooking as a form of "chemical" science and collected globes, instruments and books by European experimentalists.

⁸ Whereas in Europe alchemists and natural philosophers contributed significantly to the development of scientific ideas and practices, the viceroys of New Spain tended to fund scientists who demonstrated their skills with mathematics for problems of relevance to the administration of government. (On the role of alchemists and their traditions upon the development of science in Europe, see Bruce Moran, *Distilling knowledge: alchemy, chemistry, and the scientific revolution* (Cambridge, Massachusetts: Harvard University Press, 2005), esp. 160ff.) Books on alchemy, magic, and natural philosophy were available to aspiring alchemists in Spanish America, but educational institutions provided little encouragement for such studies. Alchemists would instead apply their curiosity about nature to experiments in pharmacy and metallurgy for mining.

Besides the absence of royal whimsy, or anxiety, to fund alchemists and astrologers at court, the geographic distance from a monarch meant that toymakers had few clients for their inventive and sometimes exquisite playthings such as automata and other inspiring machines. The mechanisms contained within such remarkable amusements were sophisticated and compact solutions to everyday engineering problems.

This thesis is a study of Mexico City's diverse communities of scientists as well as their transoceanic intellectual networks and book collections. These scientific books crossed the oceans between Asia, New Spain, and Europe providing readers on the Atlantic and the Pacific with the latest observations to compare and refine their own scientific thinking with. It links the movement of people, ideas, and objects across large expanses of water and land. Amateur astronomers and hobbyists Alexandro Favián, Sor Juana Inés de la Cruz, and Melchor Perez de Soto as well as local commentators also play a role in my thesis. Hobbyists were especially productive during the early modern period when bespoke, handmade (often homemade) instruments were the norm; they also circulated new knowledge by participating in salons and overseas correspondence. With its emphasis on scientists' transoceanic intellectual networks as well as the production and distribution of scientific books, this thesis presents a big-picture narrative of the cultural and material history of science in the New World in the earliest decades of European colonization and argues that we can shift the frontier of early modern science to New Spain because it was the most active centre of scientific discourse and publication in the Americas between 1535 and 1700.

I have asked new questions of the most well-known documents—mainly pertaining to the scientists' methods of investigation: what they wrote in the margins of their books, how they structured their writings and whether they employed indigenous assistants or writings. I have also used primary sources which have been transcribed and published but have not previously been studied comprehensively, such as the correspondence between Favián and Kircher and Jaime Juan's observations of the Eclipse of 1584. In the case of Favián's Letters to Kircher, Ignacio Osorio-Romero passed away while his transcription of the correspondence was going to press; he certainly studied the letters as he worked through the palaeography of the manuscript originals in Rome, but he did not publish his interpretations. And no other scholar has published a comprehensive examination of Favián's letters. Some of my sources are unique, such as the inventory of Adrian Boots' scientific book collection and the actual books which Alexandro Favián received from Athanasius Kircher.

Unlike other studies in the history of Latin American science, this thesis explains the phenomenon of a flourishing scientific community in Mexico City during the 1700s, a period when Science in Spain began its dip into obscurity and before equivalent scientific communities were present elsewhere in the Americas. I found a

link between state economics and the vitality of scientific initiatives by looking at the work of economic historians: Flynn & Giraldez's global economic data on the Manila Galleon trade as well as Chinese and Spanish inflation; Tepaske & Cline's silver and gold mining output findings alongside John Lynch's viceregal expenditure records all show that the viceroyalty of New Spain was not only Spain's economic mainstay but that it also financed the military defense of the empire's shipping and forts.

Building on Boyer's observations about the potency of New Spain's economy and geographic location between Asia and Europe in addition to Leonard's studies of the intellectual vitality within the viceregal capital during the same time, I found that Mexico City during the Habsburg era was economically robust. It was a major stopover for European intelligentsia on their travels East, and it housed its own locally born community of thinkers on the cusp of the revolutions in science. The presence of many varied books on scientific and mathematical topics, imported and locally produced, supplied these local intellectual communities with a steady supply of fodder for new ways of thinking about the relationship between mathematics and science.

In contrast to previous research, I argued that New Spain's concentration of intellectual, financial, and institutional resources in the Americas during the early period of Spanish colonization led to a flourishing of scientific activities and communities. This claim has not yet been made in the literature. Scholars have noted the centrality and wealth of Mexico City before, but none has argued that these factors made it an especially good place for *científicos* to innovate and to publish their results. Nor have historians of Mexican Science undertaken comparative studies with other regions in Spanish America during the early colonial period in order to assess the relative scientific productivity of different cities. Nevertheless historical contingency, geography, and the existence of a leverageable pre-contact infrastructure all contributed to the early clustering of resources in Mexico City.

From the perspective of the eighteenth century when Latin America was ruled by the Bourbon Crown, the Spanish Empire was institutionally polyfocal; that is, it was endowed with the material resources of scientific activity in multiple cities. However it had taken some time for the arrival and local publication of relevant books, for communities of trained and self-taught scientists to establish themselves as well as for the local production of glass and other instruments to develop. These resources took longer to arrive in locations that were distant, in terms of transport and travel, from Veracruz and Cartagena mostly because of difficult topographies which

made them fringe areas where the rule of law was weak. The critical mass of human and material resources necessary to compete with New Spain in producing scientific works was not reached anywhere in the Americas before the year 1700 although Jesuit scientists working in the viceroyalty of Peru made notable contributions during the next century. Book collections and printing presses in the geographically tight-knit cities of Cambridge-Boston, New Amsterdam (i.e., New York), and Philadelphia also began to lay the groundwork for publications in early modern science from the mid-seventeenth century.

From the perspective of the 16th and 17th century, Mexico City had the best infrastructure of all the Spanish American cities early on for a productive scientific community. The viceroys of New Spain paid the salaries of many explorers, naturalist-physicians, different types of engineers, and cosmographers (who combined the skills of cartography, astronomy, and navigation) during the Habsburg Era. My discussions of scientific books, instruments and their owners in New Spain during this period shows that the requisite skills and human capital were concentrated alongside the cultural resources found there, and that scientists spent significant periods of their working lives interacting with one another in the viceregal capital.

Also new is my use of minority perspectives on scientific discourse at the time in Mexico City-Puebla, including the written records of women, indigenous intellectuals, travellers (Francisco Carletti, Gemelli-Carreri, and later Humboldt), and science-hobbyists, as well as non-scientist diarists (Martín de Guijo and Antonio de Robles) whose observations help to fill in the picture of a cosmopolitan and wealthy city. In particular, I have incorporated comments by the Nahua chronicler Chimalpahin on the solar eclipse of 1611 and identified the roles of four women who participated in or patronized Jesuit science: María de Guadalupe de Lencastre the Duchess of Aveiro and Countess María Enríquez Porres y Guzmán in Spain, in addition to Sor Juana Inés de la Cruz, and vicereine María Luisa Manrique de Lara. In my depiction of Mexico City and its satellite city Puebla, the new world's distance from a Europe entrenched in its own Aristotelian-educational traditions allowed mathematically-inclined figures like Diego Rodríguez and Sigüenza y Góngora to align their observations and writings with the best mathematicians and theorists emerging from contemporary European scientific discourse. Through their activities as university professors Rodríguez and Sigüenza were successful at disseminating their own observations within the Spanish Empire.

My thesis explains that the strengths of sixteenth century Spanish science—when Philip II initiated and funded a variety of scientific investigations, and Spanish works of mathematics and navigation were reprinted and translated throughout Europe—shifted geographically, to become in the seventeenth century, the strengths of New Spain’s scientific communities. Shifting the frontier, or re-centering the map, is a way of viewing a change in patronage from the Crown in Madrid to the viceroys in Mexico City. During the 1600s, Mexico City became an ‘epicentre’ of scientific discourse and scientific text production in the Americas. After Philip II’s death, economic inflation in Spain and the inability of the crown to fund scientific ventures and the study of mathematics explains the shift of the scientific frontier westward. But even under Philip II’s reign when the major scientific expeditions were initiated on the Iberian Peninsula, the king’s royal instructions to scientists came up against geographic realities in the New World. Hence, developments in the newly colonized territories ensured that the frontiers of early modern science shifted away from Europe towards the Americas and, in particular, New Spain.

This thesis has examined a wide range of primary and secondary sources in Spanish to show the circulation of early modern scientific writings produced in New Spain: it spotlights the activities of botanists, astronomers, and engineers in Mexico City from 1535 to 1700. In the case of Francisco Hernández we saw the process by which a botanical record was financed, gossiped about, excerpted, eventually published, and later rediscovered by eighteenth-century naturalists. Hernández’s aspiration to be the “New World Pliny” indeed stirred other botanists to capitalize on his achievement. For this first chapter, I consulted Hernández’s draft manuscripts at the National Library of Spain and the Ministerio de Haciendas and advanced the work of scholars Simon Varey and Raquel Álvarez-Peláez by elucidating the manuscripts’ reappearances in eighteenth-century historiography.

Chapter 2 built upon María Luísa Rodríguez-Sala’s archival discoveries to reveal the beginnings of long-distance astronomical observations with three figures: royal cosmographer Jaime Juan, who taught new astronomical methods from the Caribbean to New Spain to the Philippine Islands while calculating longitude in each; Juan de Herrera, who recommended Jaime Juan for the expedition and promoted the cause of mathematics at Philip II’s court; and cartographer Francisco Domínguez y Ocampo, whose mapmaking for both Francisco Hernández and Jaime Juan was only a thin slice of his varied scientific activities for the viceroys of New Spain. The little

known nineteenth-century study *Memoria sobre las tentativas hechas ... en España al que resolviere el problema de la longitud en la mar* (1852) regarding early Spanish attempts to ascertain longitude at sea also provided evidence of a community of practitioners for situating Juan de Herrera's own scientific instrument designs.

Chapter 3 focused on the *Relación de 1637*, Mexico City's earliest comprehensive account of the *desagüe* (drainage projects). Even though several historians have discussed engineers working in New World mines, hydraulic and civil engineers held significant posts in New Spain and yet are little known. Additionally, historians who have written about the *desagüe* have tended to focus on the flood of 1629 while this thesis has examined the official record in detail for the first thirty-three years of the drainage project and incorporated diarists' and travellers' accounts alongside indigenous perspectives on the *desagüe*. Engineers Enrico Martínez, Adrian Boot, and Fray Andrés exemplified a diversity of talents and opinions in the viceregal capital, and grappled with the political complexity of the problems they sought to resolve. I also examined the Mexican Inquisition's record of Adrian Boot's library as well as a letter from Fray Andrés to the viceroy regarding his assessment of Martínez's faulty supervision of the Huehuetoca Tunnel construction to clarify historiographic renditions of the three engineers' interactions.

Chapter 4 offered a new view of Mexico City astronomers Diego Rodríguez and Sigüenza y Góngora as they influenced and corresponded with other astronomers throughout Spanish America and global Jesuit networks. My analysis of the diffusion of *De los Logaritmos* (c.1635) and the *Libra Astronómica* (1690) expanded Elías Trabulse's studies of novohispanic scientists by examining the implications of their long-distance contacts.⁹ The writings of the indigenous chronicler Chimalpahin and astronomy-hobbyist Alexandro Favián, offered perspectives on the popular views of astronomical concepts in New Spain. My analysis of Favián's model of Athanasius Kircher's glass instrument design shows that optical lenses were produced, at least in part, by the Puebla glassworks. Other evidence demonstrates that lenses for eyeglasses and telescopes were locally available in Mexico City during a time when high-quality lenses were an expensive commodity because their production required much technical skill.

⁹ By my count, Trabulse identified 143 scientist-mathematicians, in his *Ciencia y Tecnología en el Nuevo Mundo* (1994), active in Spanish America during the sixteenth and seventeenth centuries.

In chapter 5, advancing Irving Leonard's groundbreaking studies of shipping record book lists, I examined Mexico City booksellers' inventories and Melchor Pérez de Soto's book collection to argue that the scientific book collections of New Spain demonstrate a wealth of access to early modern European thought. The chapter presents a selection of titles from the 238 mathematical-scientific works printed in Mexico City by the year 1700 and argues that the Inquisition played a minor role in censoring these books.¹⁰ The presence in Europe—during the sixteenth and seventeenth centuries—of scientific books from Mexico City printers also shows that new knowledge and scientific ideas traveled in both directions across the Atlantic.

This thesis has explored the production and circulation of scientific knowledge within Spain's vast empire from 1535-1700. It identifies Mexico City as a resource rich, central node within overlapping networks of scientific travel and discourse. Historical records produced in New Spain have demonstrated how mathematical-scientific ideas in the Americas reflected, and for brief moments anticipated, particular value shifts in contemporary European scientific discourses.

¹⁰ My count of scientific and mathematical works produced in Mexico City by 1700 is based upon bibliographical data supplied by the Catálogo Colectivo de Impresos Latinoamericanos.

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