The mindful hand

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The mindful hand

Inquiry and invention from the late Renaissance to early industrialisation

Edited by
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Illustration cover: The 'horticultural' method of drawing an ellipse as illustrated by Van Schooten in *La Dioptrique*.

The hand is the cutting edge of the mind

– Jacob Bronowski

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Lissa Roberts
November 2006

How to read this book

This is an ambitious book, composed with a number of purposes and audiences in mind. To accommodate these various goals and publics, we would like to propose a number of possible reading strategies. While every reader obviously has their own favourite way of approaching a text, we offer the following advice.

For readers who are simply interested in savouring a number of well-crafted essays on the history of natural inquiry and invention – normally spoken of as the history of science and technology – the book can, of course, be opened anywhere. To gain a sense of historical development through time, we suggest that you read the essays in the order that they appear.

A primary aim of this volume is to suggest a unified narrative that stretches between the so-called Scientific Revolution and the early years of the so-called Industrial Revolution. Our hope is that both historians of science and historians of technology will take the time to consider our argument that the history of inquiry and invention during this extended period is a complex story of complicity between contemplation and manipulation. It is a story that cannot be explained in terms of the causal relationship between theory and practice or – to use anachronistic terms – science and technology. For those who like to approach such claims from the level of empirical detail, we suggest that you skip the book's preface and go straight to the introductions of our four sections. Read these back-to-back for an overview of the individual topics and themes upon which the volume's broad historical claims are based. Then fill this sketch in by reading the individual essays themselves.

In the preface to the entire volume, we bring together a discussion of the book's historical content and historiographical commitments with its broader, polemical mission. Readers prepared to dive in headfirst and consider the layered reasons that gave shape to this book, will want to begin here. The message that should then stay with such readers as they subsequently make their way through the volume's individual essays is three-fold. First, Cartesian dualism does not provide an accurate grid upon which to chart the history of inquiry and invention. The history of material and knowledge production, in other words, is a single, hybrid affair in which the work of the head and of the hand formed a complex whole. Second, the history of inquiry and invention is not a history of the relationship between science and technology, or of the relationship between theory and application. The examination of nature was just as likely to involve and contribute to material production as invention was to the production of knowledge. Third, this vision of the past speaks to the long-term existence of a productive regime very much like what is currently advocated by sociologists and science policy experts in terms such as transdisciplinarity and 'mode two' technoscience. If this point is granted, current policy initiatives to redirect university research toward market and society-driven demands must be seen as wrong to begin with an onslaught on 'traditional' research as socio-economically non-engaged and non-productive.

Our hope is that this book will reach a large and varied audience. We would like to see it read critically by colleagues in all fields concerned with the past, present and future of science and technology. We'd also be quite pleased to have its essays included in university course curricula, so that students are drawn to consider the impact of our approach on their own field of study. And if the content and implications of our stories have a hand in changing the minds of those who deliberate on the policies that shape research and education, so much the better.

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Preface

Lissa Roberts and Simon Schaffer

Neither the naked hand or the understanding left to itself can effect much.
Francis Bacon, *New organon*[1]

So reads the second aphorism of the book in which Bacon heralded a new and powerful regime of production. While many have celebrated Bacon's message as announcing the birth of modern science, *The mindful hand* responds to an important assumption that undergirds his aphorism, one that continues to sustain many of the discussions that have shaped western understanding and attitudes toward material and knowledge production. For even as it seeks somehow to connect the work of the hand and that of the mind, it assumes a fundamental distinction between them.

Commentators have assigned mental and manual labour to two essentially different categories since at least the time of Aristotle: witness the classical opposition of *epistemē* and *technē*.[2] This distinction took on new significance, however, in the specific historical milieu that also saw the emerging dominance of early-modern European markets and political economies. Not only did its re-assertion help make a space for analysing the relations between the purportedly separate realms of mental and manual deeds and goods. In a society of orders, the steeply graded hierarchy of head and hand was vital to defining persons and their social places. Unsurprisingly, then, fierce struggles attended the establishment and governance of the mixed regime of material and knowledge promulgated by Bacon. These fights are all the harder to recover whenever historians effortlessly accept and assume this same categorical distinction.

Considerable energy was certainly needed to make such hierarchies of head and hand ever seem plausible. Even more effort was needed to turn this

[1] Francis Bacon, *The new organon,* edited by Fulton Anderson (New York: Bobbs-Merrill, 1960), p. 39.

[2] The *topos* of lowly artisans and noble citizens was developed in Aristotle's *Politics*, parts 7 and 8. Compare Benjamin Farrington's Marxist approach to this theme in his *Head and hand in ancient Greece: four studies in the social relations of thought* (London: Watts, 1947) with his *Francis Bacon: philosopher of industrial science* (London: Lawrence and Wishart, 1951). Canonical accounts of the problem include Paolo Rossi, *Philosophy, technology and the arts in the early modern era* (New York: Harper and Row, 1970) and the essays gathered in Edgar Zilsel, *The social origins of modern science*, edited by Diederick Raven and Wolfgang Krohn (Dordrecht: Kluwer, 2003).

distinction into an unremarkable, indeed self-evident, fact of life. This is surely why it is so difficult to tease apart the enterprises of socio-political life, knowledge-making and material relations involved in such a distinction: we are, in short, the heirs of those enterprises. Self-appointed mental workers, such as philosophers, scientists, policy-makers and bureaucrats, then as now, claimed and constructed the dominion of their 'understanding' over hand-workers and their crafts. They relied on the mutual reinforcement of coercive rhetoric and brutal deed. The easy acceptance of their categories has left us with a historical map shaped by oppositional and hierarchically ordered pairs: scholar/artisan, science/technology, pure/applied and theory/practice.

Maps count as potent resources, whether in the geodetic projections first designed in Renaissance Europe that exaggerated the scale of the new imperial powers, or in the social projections that attributed overweening powers to the clerical masters of mind and spirit.[3] The long aftermath of these cartographies continues to exert its effects. Cold War polarities much aided the seeming obviousness of stern contrasts between head and hand as well as the legitimacy of stories that asserted the higher historical role of the cerebral and the intellectual in making modern knowledge regimes. Contemporary academic policy discussions obsess about an allegedly desirable new regime that would overcome such dualities and would have knowledge made in the context of application. Yet this kind of atavistically Baconian policy-talk precisely reinforces a hierarchical split it notionally avoids. Socially responsible historians have to ask what is entailed in this visionary regime of knowledge production: we have to find out whether and how it differs from what has preceded it.[4]

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[3] J.B. Harley, *The new nature of maps: essays in the history of cartography*, edited by Paul Laxton (Baltimore: Johns Hopkins University Press, 2001), pp. 83-108; David Buisseret, *The mapmakers' quest: depicting new worlds in Renaissance Europe* (Oxford: Oxford University Press, 2003); Richard W. Haddon, *On the shoulders of merchants: exchange and the mathematical conception of nature in early modern Europe* (Albany: SUNY Press, 1997); Amir Alexander, *Geometrical landscapes: the voyages of discovery and the transformation of mathematical practice* (Stanford: Stanford University Press, 2002).

[4] That the Cold War was a very productive era for such histories is evidenced by the work written then by authors as varied as Alexandre Koyré in the history of science and Walter W. Rostow in economic history. As mentioned frequently in this volume, Koyré was instrumental in promoting a vision of history in which ideas were the motor of scientific development. Rostow, advisor to American presidents as well as an economic historian, situated the introduction and spread of 'Newtonian knowledge' as the turning point in modern western industrialisation. See, among other publications, Alexandre Koyré, *From the closed world to the infinite universe* (Oxford: Oxford University Press, 1957) and W.W. Rostow, *The stages of economic growth: a non-communist manifesto* (Cambridge: Cambridge University Press, 1960). For the need to stimulate a 'new' productive regime, see Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott and Martin Troy, *The new production of knowledge: the dynamics of science and research in contemporary societies* (London: Sage, 1994) and Helga Nowotny, Peter Scott and Michael Gibbons, *Rethinking science: knowledge and the public in an age of uncertainty* (Cambridge: Polity Press, 2001).

As part of this conversation, *The mindful hand* questions the historical validity and efficacy of these oppositional categories, on which so many history and policy pronouncements are built. In just the period all too typically associated with the rise of modern science and technology, roughly between the late Renaissance of the final decades of the sixteenth century and the emergent industrialisation of the later eighteenth century, material and knowledge production regimes were indeed much informed by just these assumptions about such polarities of head and hand. We want to examine how this could be. This makes our book relevant to discussions normally located well within the separated disciplinary realms of a history of science organised round a unique Scientific Revolution and a history of technology organised around a singular Industrial Revolution.

This is certainly not the first attempt to bridge this disciplinary gap, nor the first to consider the history of material and knowledge production during this extended period within a single volume.[5] But our approach is distinctive. The essays that follow replace essentialism with an insistence that the establishment and exploitation of explanatory categories are part of the histories that need to be told. We eschew *a priori* formulae that equate science and its claimed predecessors with knowledge, or identify technique with application. Instead, we focus on the specific sites in which material and knowledge production jointly took place, as well as the surrounding struggles to separate and reorder the processes, personnel and products of such economies. Our book is dedicated to the mindful hands and handy minds that collaboratively engaged in inquiry and invention between the late Renaissance and early industrialisation.

After the revolutions, in pursuit of modernity

This book arises from a workshop held in Amsterdam in September 2004. Contributors were invited to present papers that described specific historical

[5] Surveys are provided in A.E. Musson and Eric Robinson, *Science and technology in the industrial revolution* (Manchester: Manchester University Press, 1969); Peter Mathias and John A. Davis, eds., *The first industrial revolutions* (Oxford: Blackwell, 1989); Margaret Jacob, *Scientific culture and the making of the industrial West* (Oxford: Oxford University Press, 1997); Maxine Berg and Kristine Bruland, eds., *Technological revolutions in Europe: historical perspectives* (Cheltenham: Edward Elgar, 1998); Joel Mokyr, *The gifts of Athena: historical origins of the knowledge economy* (Princeton: Princeton University Press, 2002). For the specifics of Anglo-French development, compare also Henry Heller, *Labour, science and technology in France 1500-1620* (Cambridge: Cambridge University Press, 1996); Larry Stewart, *The rise of public science: rhetoric, technology and natural philosophy in Newtonian Britain 1660-1750* (Cambridge: Cambridge University Press, 1992); Liliane Hilaire-Pérez, *L'invention technique au siècle des lumières* (Paris: Albin Michel, 2000). For useful bibliographical critique, see Ian Inkster, 'Discoveries, inventions and industrial revolutions: on the varied contributions of technologies and institutions from an international historical perspective,' *History of technology* 18 (1996): 39-58 and Leonard N. Rosenband, 'Never just business: David Landes, *The unbound Prometheus*,' *Technology and culture* 46 (2005): 168-176.

sites where inquiry and invention coalesced with productive results during the period between the late Renaissance and closing years of the long eighteenth century. The workshop enjoined participants to use the words 'science' and 'technology' as infrequently as possible and to adopt the assumption that investigating nature depended as much on material inventiveness as invention in fact entailed inquiry into nature. Natural philosophers were to be understood as bodily engaged producers while the mental dexterity of artisans and craftsmen was to be made as apparent as their manual abilities. This was not simply a question of showing that philosophers were a handy lot or that artisans and craftsmen were capable of thought. It was a guide for recovering the hybrid activities involved in the intimately related processes of material and knowledge production.

Much of the real work began after the workshop as we sought to understand the consequences of our collaboration and to transform a set of individual papers into a coherent volume of essays. What historiographical lessons could be drawn from the guidelines we had set? What historical images emerged of the broad geographical field and chronological period traversed by our studies? What might our volume add to current discussions surrounding the valorisation and governance of knowledge production?

Concern with the ways in which Europeans developed reliable knowledges and practical techniques in the period under investigation here has long been taken as fundamental for a very wide range of past and contemporary problems. Urgent questions about the process of modernisation, the transition to industrial society, the relation between research and application and the proper roles of state, market and public have often been addressed by telling stories about this period and these processes. Indeed, it's a good bet that each and every tale of the way Europeans linked their knowledge and their technique and how these linkages changed between 1550 and 1800 has been organised to give a recipe, or offer a warning, about modernisation and the proper status of experts and practitioners.[6] We thus see it as one of our tasks to reflect decisively on the very terms historians can use to tell better stories and provide better maps of the relation between inquiry and invention. Instead of taking our explanatory categories for granted, we need to give them their proper histories too.

The predominant structure of stories told about modernisation and industrialisation is a good place to start. The end-point of such stories long seemed self-evident. Global modernity was characterised by the authority of science as

[6] Michael Adas, *Machines as the measure of men: science, technology and ideologies of western dominance* (Ithaca: Cornell University Press, 1989); John Staudenmaier, *Technology's storytellers* (Cambridge, MA: MIT Press, 1985).

the best if not only account of nature and by the power of technology as a means of mastering nature's capacities in the service of economic welfare. One was supposed to appeal to past dramatic revolutions to describe how this world emerged: a Scientific Revolution, located in western Europe in the sixteenth and seventeenth centuries and an Industrial Revolution, located first in Britain and then elsewhere from the later eighteenth century.[7] But neither revolution wins easy favour among historians now, nor is it clear how these revolutions were supposedly related.

There are many challenges to these received views. Significantly, they speak to the enterprises generally examined by both historians of science and historians of technology. *First*, the very existence of unique Scientific and Industrial Revolutions has been severely questioned, their definitions extensively analysed and criticised.[8] *Second*, we generally accept that there was no solitary entity such as science before the nineteenth century: Anglophones stay unusual in their notion of *science* in the singular as a unique form of reliable knowledge devoted entirely to nature. Nor did the notion of *industry* have anything special to do with machino-facture before the nineteenth century: industrial mechanisation did not then diffuse, inevitably and inexorably, from the British Isles towards less industrially enlightened lands.[9] *Third*, articulations between knowledge, know-how and technique were intimate and complex. Distinguishing between high-status sciences and lowly labour obscures much more than it reveals and is extremely anachronistic. Likewise, privileging discovery and invention over appropriation and use distorts visions of historical development.[10] *Fourth*, whatever its universal pretensions and efforts at standardisation, what is now called scientific knowledge is made in local and mundane ways. It depends on no especially genial or excessively rational methods, relies on the situated work of persuasion and credibility and tends often to be embodied in ingenious and artful labour. Its production requires and reinforces specially organised places where this labour is performed and between which it is

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[7] Roy Porter and Mikulas Teich, eds., *Revolution in history* (Cambridge: Cambridge University Press, 1986), chapters 13 and 14.

[8] For some recent revisionism see Steven Shapin, *The scientific revolution* (Chicago: Chicago University Press, 1996), Maarten Prak, ed., *Early modern capitalism: economic and social change in Europe 1400-1800* (London: Routledge, 2001) and Rondo Cameron, 'A new view of European industrialisation,' *Economic history review* 38 (1985): 1-23.

[9] Andrew Cunningham and Perry Williams, 'De-centring the 'big picture': the origins of modern science and the modern origins of science,' *British Journal for the History of Science* 26 (1993): 407-432; Christine MacLeod, 'The European origins of British technological predominance,' in L.P. de la Escosura, ed., *Exceptionalism and industrialism: Britain and its European rivals 1688-1815* (Cambridge: Cambridge University Press, 2004), pp. 111-126.

[10] David Edgerton, 'From innovation to use: ten (eclectic) theses on the history of technology,' *History and technology* 16 (1999): 1-26.

distributed.[11] Much the same can be said of the spread and transfer of technology and the globalising regimes in which they occur. The planetary extent of networks of trade, knowledge, hardware and commodities was certainly decisive for the new systems of learning and production in early modern Europe, as it is now.[12] The violent dramas of technology, commodity and capital transfers between North and South since the 1960s and the struggles for and against globalisation have taught us anew how the creation of global markets necessarily implicates a simultaneously productive and disruptive tension between local idiosyncrasy and long-range standards.

New modes for old: beyond science and technology

Our approach helpfully challenges the perversely unilinear model that continues to haunt much scholarship. Science is generally identified as knowledge production. In this scheme, once knowledge is produced it is then applied, exploited and turned into effective technique.[13] Recent sociologists of science and technology concerned with the apparent alienation between academic science and the realms of social and economic production have pointed to the establishment of a new ('mode two') regime in which knowledge acquires greater robustness and effectiveness because it is produced in the context of application. While this scheme is meant to breach the barrier allegedly separating science from material productivity and social relevance, it nevertheless retains the identification of science with knowledge and reinforces a ('mode one') historical vision of science and technology as occupying opposing camps of 'pure' and 'applied'. [14]

On this showing, the historian's task would simply be to start with a detailed analysis of the production of specialist expert knowledge, then to trace the path through which it was turned into marketable value and efficient machinery. But little of this picture makes historical sense. This is just what is at stake in this volume. Most of what is taken to characterise the 'new' production of

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[11] Steven Shapin, 'Here and everywhere: sociology of scientific knowledge,' *Annual review of sociology* 21 (1995): 289-321, pp. 304-307; Dominique Pestre, 'Science des philosophes, science des historiens,' *Débats* 102 (1998): 99-106.

[12] Peter Linebaugh and Marcus Rediker, *The many-headed Hydra: sailors, slaves, commoners and the hidden history of the Revolutionary Atlantic* (Boston: Beacon Press, 2000) is an essential starting point. Compare Steven J. Harris, 'Long-distance corporations, big sciences and the geography of knowledge,' *Configurations* 6 (1998): 269-304 and the essays in Paula Findlen and Pamela Smith, eds., *Merchants and marvels: commerce, science and art in early modern Europe* (London: Routledge, 2002).

[13] On the 'linear model' see Karl Grandin, Nina Wormbs and Sven Widmalm, eds., *The science-industry nexus: history, policy, implications* (New York: Watson, 2005).

[14] Michael Gibbons et al, *The new production of knowledge* and Helga Nowotny et al, *Re-thinking science*.

knowledge is in fact rather old. These features also typified much knowledge production in Europe between 1550 and 1800. Knowledge was made in contexts of application, disciplines were fluid, work took place across many social sites, there was pervasive reflection on the grounds of knowledge in the process of making knowledge and, of course, it was necessary and difficult to assess knowledge quality in systems of distributed and mutable trust and credit. Once again, it is the very notion of science as 'knowledge production' that needs critical reanalysis here.[15]

This volume shows that it is preferable simply to refuse an identification between the production of knowledge and some category such as science. It is insisted here that ingenious aptitude and social circulation mattered much to the way inquiry and invention functioned in our period. Instead of seeking a procrustean framework that would fit the entire process of refined knowledge and applied ingenuity into a revolutionary narrative of startling modernisation, the essays gathered here interrogate the very terms of analysis historians have favoured: theory, practice, ingenuity, (o)economy and inquiry. These were words and notions made and remade in the period we analyse in this book. An important implication for historians, sociologists and policy makers is that 'pure' science is better seen as a rhetorical category put to work for various purposes of persuasion than an objective description of the content and goal of scientific work.

As an initial move, we adopt a much more synchronic approach to the knowledges and techniques developed in Europe between the mid-sixteenth and the early nineteenth centuries. It is within such a context that we seek appropriate terms and tools with which to make sense of the systems of ingenuity and invention in place during that period. We do not assume a prior polarity that would distribute reliable knowledge and effective action between two adamantine categories, roughly identifiable as science and technology. This means we don't then have to work out how such utterly sundered ways and goals of producing ever interacted. Instead, we accept that this world was made up of a regime both hybrid and interlinked. Ingenuity, know-how and sets of skills mattered in studios and libraries, workshops and markets, courts and mills. And instead of searching for a splendid narrative structure that would carry European cultures from primitive accumulation inevitably to industrial enlightenment, the studies gathered here want to make sense of specific articulations between different versions of ingenious knowledge and knowledgeable techniques. The aim is then to map an entire regime of hybrid productivity that governed European ways of doing and making.

[15] Dominique Pestre, 'The production of knowledge between academies and markets,' *Science, technology and society* 5 (2000): 169-181 and idem, 'Regimes of knowledge production in society: towards a more political and social reading,' *Minerva* 41 (2003): 245-261.

This attempt at reorientation gains strength from a comparable and recent reorganisation within the histories of science and technology. Instead of chronologies, it has become popular to examine geographies. It is not immediately clear how this change is supposed to help or work. To be sure, historians spend less time on establishing priorities and more on analysing co-ordination. They need no longer ask who first admirably identified photosynthesis, somehow setting out the visionary theory on which all subsequent agronomy allegedly depended, or who first experimentally revealed specific heats or did trials with stationary steam engines. Instead, historians are drawn to ask how a crop technique or a fire-machine that flourished in one field was ever effective across social and technical space, how use was part of routine custom and about the complex practical rationales for these judgements and habits.[16]

But this approach needs care. Both localisation and spatialisation mattered. Spatialisation, variously represented through terms such as diffusion and popularisation, has been a common concern for historians of science and technology. It is at least as important to stress that all reliable knowledge and effective technique, especially in the regime that concerns us here, involve localisation: the mobilisation at a specific site of materials and techniques drawn from elsewhere. It is widely agreed that attention to circulation, exchange, co-ordination and networking should preoccupy historians' attention. What is perhaps less evident is a coherent attempt to show the intimate links between locally mobilised and spatially distributed enterprises. This coherence requires pointed critique of the notion of science simply as knowledge production. It also requires us to challenge a model of ingenuity and invention that focuses on local innovation followed by widespread adoption, a model that reproduces the problems of linearity. We need a synchronic account of the intimate ways in which all sites of knowledge making and technique were implicated in networks of skilled practice and of mobile collaboration. A history of this early modern regime must therefore be a history of travel, commerce and governmentality.

This challenge thus requires refusal of the dichotomy of local innovation and widespread adoption by refusing to identify and privilege knowledge-making as a prior, entirely cerebral, scientific inquiry. A new geography reconsiders the topography of an apparent gap between local know-how and widespread principles. Work developed in this book should not at all be read as a simple reorientation from universal axioms towards craft practices. To be sure,

[16] Jon Agar and Crosbie Smith, eds., *Making space for science: territorial themes in the shaping of knowledge* (Macmillan, 1998); David Livingstone, *Putting science in its place: geographies of scientific knowledge* (Chicago: Chicago University Press, 2003).

the typical knowledge form presented in this volume's essays is not rule-governed calculus but rather a somewhat unspecifiable family of embodied skills. The characteristic location is switched from panoptic classroom to messy workshop. On the one hand, we encounter the sciences as far-reaching metrological systems, networks dependent on the painstaking distribution of legally enforced numerical standards. On the other, we find them as enterprises of tacit capacities, ineffably embodied in competent practitioners.

Quite similarly, we recognise local technological projects of invention and innovation as governed by the tacit genius of on-the-spot practitioners. Discussions of technology diffusion and transfer, meanwhile, invariably invoke the necessary presence of trans-local standards upon which successful spread and adoption are seen to depend. A pressing question arises: what could be the relation between co-ordination through uniform procedures and measures, on one hand and reliability through tacit training on the other? Two possible answers emerge from this book, one that speaks to a reorientation toward what we might call practical or 'cunning' intelligence, the other that directs our attention to the political nature of standardisation projects – the history of which always entails a productive tension between local assertions of and resistance to power.

The notion of 'cunning' or practical intelligence raises fascinating questions about the possibility of specifying the embodied locus of a practitioner's competence. It further offers a way to navigate analytically the claimed separation between tacit knowledge, confined to its mundane locales and the seemingly alien world of universal principles, whose powers were supposedly enacted in global values. A very ancient tradition reinforced the distinction between the imperium of exact standards and the pursuits of cunning intelligence, the *metis* of the Greeks.[17] Cunning intelligence was akin to animal instinct, evident in the successful conjectures of ship's pilots, a set of ingenious semiotic skills proper to carpenters, politicians, physicians and midwives. Crucially for our understanding of the role of *metis* in the processes of knowledge production, Greek commentators reckoned that it was the very nature of things that made cunning intelligence powerful. Because citizens, diseases and seaways were multiple and shifting, their mastery required multiply shifting skills. Those epistemologists who denied shifting ontologies in favour of ideal types denounced cunning methods. Intellectual historians of technologies and sciences, much indebted to platonising philosophies of knowledge, sweepingly damned practical intelligence as a plausible source of rational science. Cunning might be involved in the recalcitrance of local circumstances and materials; but how could it

[17] Marcel Detienne and Jean-Pierre Vernant, *Cunning intelligence in Greek culture and society* (Hassocks: Harvester, 1978).

ever show the value of and provide values for universal laws? No doubt this condemnation has informed the sense that rationalist standardisation and cunning intelligence cannot easily be combined in the sciences. Yet they can be combined and in the cases considered here often were.

Standardisation is rightly a crucial theme in the history of technology as well as science. While labour historians, especially, have long pointed to the local struggles entailed in achieving and policing standardised production methods, less attention has been paid to the interplay between the rationalising efforts of bureaucrats and factory managers and the micro-physics of rationality as a circulating system of epistemological and ontological authority. Neither has sufficient attention been given to the way in which fundamental definitions of nature and the organisation of engineering know-how have buttressed each other to reconstruct the landscape of nature's oeconomy. Exponents of rationality and standardisation quite deliberately sought to construct productive regimes in interested, improvised and complex ways using the resources provided by modes of social existence.[18] In the social mode that concerns us, roughly characterised as made up of urban elites, entrepreneurial bourgeoisie, communally organised artisans, national churches, aggressively absolutist fiscal-military states and long-range joint stock corporations, these practitioners concocted productive systems that they reckoned could be put to work as regulative regimes.[19] These regimes simultaneously helped define the attributes of bearers of knowledge and skill as well as the contents of the known world. So productive regimes such as that described here are best understood as ways of world making. They are ontologically active. In the tales told here of waterworks and mills, of print shops and dockyards, of libraries and instrument shops, we learn how knowing the world afresh always involves the production of new objects, novel commodities and innovative collaborations.

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[18] Joseph O'Connell, 'Metrology: the creation of universality by the circulation of particulars,' *Social studies of science* 23 (1993): 129-173; M. Norton Wise, ed., *The values of precision* (Princeton: Princeton University Press, 1995); Ken Alder, 'Making things the same: representation, tolerance and the end of the Ancien Regime in France,' *Social studies of science* 28 (1998): 499-545; Arne Hessenbruch, 'The spread of precision measurement in Scandinavia, 1660-1800,' in *The sciences in the European periphery during the enlightenment*, edited by Kostas Gavroglu (Dordrecht: Kluwer, 1999), pp. 179-224; David Noble, 'Social choice in machine design: the case of automatically controlled machine tools,' in *The Social Shaping of Technology*, edited by Donald MacKenzie and Judy Wajcman (New York: MacGraw Hill, 1999), pp. 161-176.

[19] John Brewer, *The sinews of power: war, money and the English state* (New York: Knopf, 1989); Michèle Fogel, *Les cérémonies de l'information dans la France du XVIe au XVIIIe siècle* (Paris: Fayard, 1989); Peter Becker and William Clark, eds., *Little tools of knowledge: historical essays on academic and bureaucratic practices* (Ann Arbor: University of Michigan Press, 2001); Miles Ogborn, *Spaces of modernity: London's geographies 1680-1780* (New York: Guilford, 1998), ch.5; Daniel Headrick, *When information came of age: technologies of knowledge in the age of reason and revolution, 1700-1850* (Oxford: Oxford University Press, 2000).

This book involves an attempt to overcome and to depart from a potent distinction between celestial knowledge and temporal power. The very status of reliable knowledge in early modern Europe seemed often to hinge on its denial of cunning, technique and use. Because directed towards divine purpose, its implication in social life was allegedly limited. Even when enunciated in a secular manner – disinterestedness as a mundane, saintly counterpart to the concerns of natural theology – the goals of knowledge production were often claimed to be circumscribed by the ideal of knowledge for its own sake. Either way, this is what marked the pursuit of natural knowledge as noble and its practitioners as trustworthy. However contested, the legacy remains in the Mertonian claim of disinterested science and the image of scientists as secular priests and servants of the truth. And it lurks behind much of the rightfully fearful protest that the regime described as 'mode two' is dangerous precisely because it risks aligning science so intimately with the brutally capitalist urges and desires of the market. [20]

If ambitious savants often took the high ground of intellectual sanctity, it was just as common for them to announce their indispensability to the state and church, to the market and the navigator. Their knowledge and skills were hence powerful because secluded, yet powerful also because networked and productively effective. Moderns will recognise the pattern. Europe of the classical age between the Wars of Religion and those of Napoleon Bonaparte spawned the regime that energetically manipulated this seeming paradox. The essays gathered here seek to help map that regime, make sense of its pathways and its ironies and thus to produce a new and useful chart of the links between quite various forms of knowledge and power. In common with Foucauldian approaches, the pattern sought is the characterisation of assumptions and prohibitions, of what was commonly practised and what was rare, with the view of evoking an entire system of productive know-how.[21] The first section of the book therefore charts the means through which enterprises of skilful measurement and craft practice were involved in forging images of pure knowledge in

[20] Steven Shapin, 'Discipline and bounding: the history and sociology of science as seen through the internalism-externalism debate,' *History of science* 30 (1992): 333-369 and idem., 'A scholar and a gentleman: the problematic identity of the scientific practitioner in early modern England,' *History of science* 29 (1991): 279-327; William Clark, 'The misogyny of scholars,' *Perspectives on science* 1 (1993): 342-357; Jan Golinski, 'The care of the self and the masculine birth of science,' *History of science* 40 (2002): 1-21. Compare Robert N. Proctor, *Value-free science? Purity and power in modern knowledge* (Cambridge, MA.: Harvard University Press, 1991) and Judith Zinsser, ed., *Men, women and the birthing of modern science* (DeKalb: Northern Illinois University Press, 2005).

[21] Peter Burke, *A social history of knowledge: from Gutenberg to Diderot* (Cambridge: Polity Press, 2000).

the sixteenth and earlier seventeenth centuries. Subsequent sections explore the early modern economy as a system of managing the capacities of nature and human labour in the name of political and social power; and of the work of state-sponsored and commercially-motivated experts in making new ways of knowledge and technique.

The mindful hand: an overview

This preface distils the general arguments suggested by our book's nineteen essays and two epilogues. Each of the richly detailed historical studies that follow provides its own lessons and implications. These essays introduce us to hybrid sites and activities that range from private Renaissance libraries, where discussions about cannons and comets simultaneously charted physical and social trajectories, to public debates over gas-lighting schemes that illuminated urban streets and industrial fortunes. In order to draw our readers' attention to the broader historical themes around which these essays cluster, we have divided the volume into four sections. Two examine historical episodes from the late Renaissance through seventeenth century. Two others focus on the long eighteenth century.

The first section, entitled 'Workshops of the hand and mind,' takes us back to a set of sites normally separated by retrospective maps that distinguish between mental and manual labour. We find here instead important commonalities among the activities and discussions held in Renaissance and early-modern Italian libraries, in ateliers of German goldsmiths, workshops of French instrument-makers and Dutch university classrooms. Heroes of the so-called Scientific Revolution, as well as their patrons, did more in such key locations than rub shoulders with gunners and craftsmen. It was out of their intimate engagement, in which famous philosophers such as Descartes and Galileo worked with their hands while lesser-known artisans and instrument-makers laboured with their minds, that co-ordinated material and knowledge production took place. Some feared the consequences of such social trespasses and simultaneously sought refuge in attributed differentiations – whatever their collaborative activities, gentlemen were deemed geometers, for example, while artisans remained mathematicians or mathematical practitioners. Others, equally cognisant of such consequences, tried to breach the walls of social division precisely by adopting the gentleman's mantle of polite attribution. Thus did aspiring commoners cum philosophers court the very distinctions that structured the socio-cultural ladder they sought to climb.

That such productive collaborations were simultaneously conservative and innovative is further demonstrated in this book's second section, entitled 'Nature's oeconomy'. Here we encounter discussion of four historical projects dedicated to engineering nature on a large scale for human use: the construction of a reliable water supply for Renaissance Rome, the draining of the English Fens, the creation of the Beemster Polder and the building of the Canal du Midi. All these large-scale projects brought water management together with territorial administration in the name of an idealised past and an equally idealised future. Caught in these projects' networks were projectors and local residents, investors and advisors, who envisioned nature in a variety of ways. Thus these projects were variously modelled on biblical Eden and Imperial Rome, pastoral Arcadia and geometrical perfection. Struggles to control the environment by re-engineering and managing the forceful elements of nature's productivity can be read as variously involving a clash or productive tension between such contending visions.

So, also, did the establishment of profitable sovereignty over nature's oeconomy variously involve intimate collaboration and strife between socially disparate groups. Ambitious government officials, investors and projectors could achieve little without the collaboration of ingeniously skilful artisans and labourers or the acquiescence of local residents. But, if the socially and politically coercive mechanisms at their disposal surprise us little, the paths and products of co-operation do not conform to similar expectations. Rather, as is repeatedly stressed in this volume, collaboration involved an intimate marriage between contemplation and manipulation. Thinking about nature and physically altering the environment proved inseparable parts of a dynamic and complex whole as the landscape was engineered through the imposition of methods and inventions that simultaneously embodied the conservative urges of tradition and the challenges of pending exploitation.

Appreciation for such complex regimes of productive activity requires us to analyse both particular sites of production and the communicative travels that connected them. We focus on the question of charting such 'geographies of skill' in the third section of this book. Concerned to expand the scope of our investigation to the period increasingly connected to projects of industrialisation, the four essays in this section and that which follows treat topics situated in the long eighteenth century. Some claim the contours of this age involved the conception and spread of 'useful Newtonian knowledge' to sites where it was inventively applied, ultimately leading to a juggernaut of industrialisation as feedbacks from technological innovation reinforced scientific progress. The cases examined here tell a rather different story. So too do they trace a rather different geography, one that neither originates in nor emanates out from Great Britain. Finally, while others refer to the claim that the spread and adoption of 'Newtonian knowledge' gave birth to industrial innovation as a 'cultural history,' we show natural inquiry and invention to have been situated in a rather differently constituted cultural matrix.

In this section we follow the early career of steam technology in the Netherlands, which most certainly did not entail the application of Newtonian knowledge to mechanical practice. Steam-driven apparatus were indeed employed to exemplify physical principles in a way that was labelled Newtonian for locally significant, rhetorical reasons. But this in no way determined the course of its application to the Dutch landscape, where a much broader range of cultural factors directed the local appropriation of inventions and ideas. Likewise, the history of German chemistry does not conform to such a historical model; no wonder that chemistry is so superficially treated in such narratives, despite its obvious centrality to the history of industrialisation. Here we learn that the fluidity between the mundanely practical orientation of pharmaceutical chemistry and the officially theoretical nature of its academic counterpart was actualised by a shared material culture. Thus were apothecaries (both in the German lands and beyond) so often at the cutting edge of conceptual deliberation while academic chemists engaged in both practical and profitable enterprises of chemical production.

Moving back to the streets and dockyards of London, we encounter the struggles through which management of material production came to depend on control over the iconic resources of knowledge production. It was out of these struggles that terms such as theory, experiment, reason and work came to occupy the spaces carved out by their modern distinctions. If transgression of such boundaries posed social and political dangers in the volatile decades of the late eighteenth century, so do their acceptance today do violence to the histories we strive to uncover.

Our attempts to show the intimate link of contemplative and manipulative knowledge must therefore take actors' vocabularies seriously: it was only at the very end of our period, for example, that 'art' came to be associated with genial creativity sundered from the work of material production and 'industry' shifted from naming socially-distributed diligence to referring to the systems of organised and mechanised manufacture. Our book's fourth section shows such shifts were part of profound reorganisations of the relation between artisan craft and the public realm. We address the questions of how ingenious techniques could be translated, how specifically skilled operatives could shift their labour or be prevented from so moving and how local tools and commodities could be more widely distributed and applied. In such spectacular innovations as the development of gas lighting, for example, firework showmen turned their lights to profit and themselves into businessmen running profitable lighting systems in factories and cities alike. Distinctions between public realms of giddy theatrical entertainment and of sober industrial enterprise were not the self-evident cause but rather the retrospectively reinterpreted consequence of practical projects and their various audiences. This argument about the public sphere's manifold and ambiguous roles in innovation and invention can be generalised, especially because of the strong role of the state in exerting surveillance and analysis through its excise system. In Britain, comparatively effective excise systems secured protective barriers behind which fledging industries grew and excise men were agents of a process to render production processes publicly accountable. Solutions to the problems of fiscal management were also solutions to the problem of the order of public knowledge. The balance of this fourth section attends to two exemplary enterprises long taken to be exemplary of this kind of knowledge: paper and print. The mechanisation of paper production in the late eighteenth and early nineteenth centuries involved no effortless diffusion of leading British engineering to backward overseas manufactories. Rather, this was a hybrid process in which techniques from across Europe were combined to produce new sets of skills and machinery. This book, which departs from the paper world of the mathematicians' library, aptly culminates in the entrepreneurs' print shops. Fantasies of the mechanisation of reliably identical copies were rarely accurate or justified. Struggles for mastery between printers, booksellers and authors, much affected the uneven and disrupted patterns of knowledge flow. The advent of stereotyping and of the steam press, decisive in publicity's history, were episodes in the lengthy story of relations between artisans, proprietors, writers and their publics, dependent on varying notions of how the otherwise seemingly sequestered labour process could be spelt out and broken down, thus become some kind of public knowledge. Telling distinctions of reason and skill, of theory and practice, gathered crucial political force.

The essays in these four sections are accompanied by two epilogues that offer more general reflections on historiography of natural knowledge and industry. Peter Dear returns to the much-maligned term 'science' and argues that alongside its apparent incompatibility with the history of inquiry and invention addressed by this volume's essays nonetheless rests the history of an emerging enterprise that showed 'some of the more prominent characteristics of what later came to be called 'science''. Ian Inkster brings the insights of economic history and non-Eurocentrism to bear on the essays of this volume, pointing out both the beneficial implications and limitations of our book's approach.

Together the essays in this book offer accessible and closely linked arguments about the practical engagements of European carriers of knowledge and skill. Instead of assuming what the words 'theory' and 'practice' meant, they offer a new history of their appearance as important categories of understanding in European society. They present a fresh picture of the process through which enlightenment and industrialisation came to be associated. And they provide important resources for those who seek to apply lessons from the past to the governance of the future.

1. Workshops of the hand and mind

Introduction

Lissa Roberts

Necessity or not, war was the mother – as well as the child – of much invention in Renaissance and early modern Europe. And, that invention was as much mental as material. On the Italian peninsula, battling princes and imperial proxies stimulated innovations that cast the potential for destruction and defence increasingly in the context of mathematical calculation and precision. In France, the Wars of Religion cradled new forms of artisanal productivity that found supportive shelter under the *Grand Gallerie* of Henry IV's Louvre, where his ministers sought to establish a wealth-generating conservatory of arts and crafts.[1] And, if Charles VIII's devastating invasion of Italy in 1494 encouraged Italian engineers to design and construct new forms of fortifications, it was Albrecht Dürer who published the first printed treatise on the subject in Nuremberg in 1527, under the menacing shadow cast by threat of Turkish invasion.

No strangers to battling both the forces of nature and Spain, the Dutch obtained their first university in 1575 as a thank-you gift from William of Orange, for having bravely weathered Spanish assaults. Soon thereafter, as part of what would come to be seen as a military revolution, Prince Maurits gave instructions that transformed Leiden University's fencing school into Europe's first official engineering school. With an innovative curriculum developed by Simon Stevin, Maurits hoped to train a cadre of military engineers worthy of the name bestowed on the Netherlands by its English neighbours: the 'university of warre'.[2] Whatever the school's military benefits, however, the majority of its graduates chose more civil careers, taking up professions such as surveying in an ambient context of innovative land reclamation and development. (See Alette Fleischer's essay in the following section.)

[1] Henry Heller, 'Primitive accumulation and technical innovation in the French Wars of Religion,' *History and technology* 16 (2000): 243-262.

[2] Geoffrey Parker, *The Military Revolution: military innovation and the rise of the West, 1500-1800* (Cambridge: Cambridge University Press, 1988), pp. 18-22; Peter Linebaugh and Marcus Rediker, *The many-headed Hydra: sailors, slaves, commoners and the hidden history of the revolutionary Atlantic* (Boston: Beacon Press, 2000), p. 32.

Across the Channel, according to a number of historians, Robert Boyle and his fellows established the Royal Society as an antidote to the chaos unleashed by years of civil war. Robert Merton's famous survey of research conducted under the society's auspices shows that a good deal of it was either directly or indirectly related to military use, especially if we include the categories of marine transport (crucial for improving naval capabilities) and mining (indispensable for arming soldiers and ships).[3] But the productive impact of war's innovative omnipresence in late Renaissance and early modern Europe extended far beyond the technological and institutional projects catalogued by Robert Merton in his dissertation and these first paragraphs. It has also been intriguingly argued that the philosophical 'mechanisation of the world picture' owes its origins, not to a scientific revolution, but a prior military one.[4]

One need only recognise the widespread analytical attention paid by natural philosophers to (ballistic) trajectories, impact and the mechanical structure of material bodies that, like a cadre of drilled soldiers, operated with machine-like co-ordination and effect, to admit at least some level of consonance between the military art of fighting and contemporary philosophy. But while most historians have examined whether and how 'science' informed military reform, it is certainly the case that war provided – at least – a formative context for philosophical developments.[5] If newly developed military tactics and discipline sought to transform the natural landscape into a choreographed theatre of forceful collisions, the 'university of warre' helped educate those both directly enrolled (including, most notoriously, Descartes) and indirectly involved to see nature more generally in mechanically disciplined terms. And just as the actualities of war exposed the local chaos that reigned within complex systems,

[3] See, for example, James Jacob, *Robert Boyle and the English Revolution* (New York: Burt Franklin, 1977); Robert K. Merton, *Science, technology and society in seventeenth-century England* (New York: Harper and Row, 1970. Originally published as part two of *Osiris: studies on the history and philosophy of science, and on the history of learning and culture* IV (1938): 360-632), chapter IX.

[4] Robert K. Merton, *Science*, pp. 201-206, 239-261; William Clark, 'The scientific revolution in the German nations,' Roy Porter and Mikuláš Teich, eds., *The scientific revolution in national context* (Cambridge: Cambridge University Press, 1992), pp. 105-107. Peter Dear, 'A mechanical microcosm: bodily passions, good manners and Cartesian mechanism,' Steven Shapin and Christopher Lawrence, eds., *Science incarnate* (Chicago: University of Chicago Press, 1998), pp. 51-82. For this theme's continuation into the eighteenth century, see Simon Schaffer, 'Enlightened automata,' William Clark, Jan Golinski and Simon Schaffer, eds., *The sciences in enlightened Europe* (Chicago: University of Chicago Press, 1999), pp. 126-165.

[5] Contrast works such as A. R. Hall, *Ballistics in the seventeenth century* (Cambridge: Cambridge University Press, 1952) and most of the essays in Brett Steele and Tamera Dorland, eds., *The heirs of Archimedes: science and the art of war through the age of Enlightenment* (Cambridge: MIT Press, 2005) with E.T. McMullen, 'The origins of Descartes mechanical philosophy,' *Georgia journal of science* 60 (2002): 127-143.

so were the material particles of mechanical philosophy's world picture(s) described as randomly colliding in a system that nonetheless revealed itself to be governed by the (divinely authored) laws of their actions and reactions. Even human society, according to the arch-mechanist and translator of Thucidides' *History of the Pelopponesian War* Thomas Hobbes, could be resolved out of the chaotically destructive 'warre of all against all,' though this required the artificial intervention of a treaty signed by the bellicose parties.

It is not the purpose of this volume, however, to argue that developments in mundane realms such as the military or the market either caused or were affected by changes in material and knowledge production. Rather, we take the intricate mesh of historical development, in which the socio-cultural and economic context simultaneously informed and was constituted by the material and knowledge production that took place within it, as a given. Also, as already discussed in the introduction to this volume, it is not our primary purpose to take issue with how the historical collaboration between science and technology should be characterised. Rather, this collection of essays questions the efficacy of organising historical inquiry around supposedly oppositional categories such as science/technology, scholar/craftsman and mind/hand. This is not to say that institutions bearing the disciplinary terms 'science' and 'technology' were never established, that social distinctions between scholars and craftsmen did not exist, or that the goals of material and intellectual production cannot be demarcated. It is instead to point out that behind all these social, institutional and product-oriented labels sits a historically complex process of hybrid activity. We can begin to see this, perhaps, by turning to two great heroes of the so-called Scientific Revolution discussed in this section: Galileo and Descartes.

Both these 'heroes', it turns out, were baptised in the heat, if not the fire, of war. As the first essay in this section, by Mary Henninger Voss, so eloquently reminds us, military matters bracketed Galileo's career. His first publication in 1606, for example, was an instruction manual for a military and geometric compass he designed nine years previously. With this instrument one could quickly measure ballistic trajectories as well as survey a battlefield or territory. But it also facilitated a wide range of calculative work done by merchants, bookkeepers, bankers and draughtsmen (actors whose collective activities also left an indelible stamp on this period).[6] What both made this all possible and recommended it to noble patrons, Galileo proclaimed, was that the compass' results were simultaneously specific and general, simultaneously practical and thought provoking. With compass in hand, Galileo wrote, he could ' in just a

[6] Pamela Smith and Paula Findlen, eds., *Merchants and marvels: commerce, science and art in early-modern Europe* (London: Routledge, 2002).

few days teach everything of geometry and arithmetic, for civilian and military use, which one cannot get by the ordinary ways without very long studies'.[7]

In fact, Galileo had his compass in hand long before taking it into the classroom. As with the telescope whereby he gained more lasting fame, Galileo designed and manufactured his compasses in the workshop he installed in his own home. Along with his tools and supplies, Galileo's residence also housed the instrument-maker with whom he worked. A more intimate level of collaboration – not at all unusual at the time – is hard to imagine. Where the art ended and the philosophy began seems really quite irrelevant to this entire endeavour.[8]

Galileo ended his publication career with the brilliant *Discourse on two new sciences* of 1638. Whatever prejudices Alexandre Koyré entertained about this work, Galileo indicated that his 'new sciences' of material strength and motion were rooted in his experiences at the Venetian Arsenal, where guns and galleys were stock in trade. It was there that 'every sort of instrument and machine is continually put in operation' by experienced artisans who, 'through observations handed down by their predecessors as well as those which they attentively and continually make for themselves, are truly expert and whose reasoning is of the finest'.[9] But how are we to understand the connection between the Arsenal as a centre of material production and wartime destruction and Galileo's book-bound reflections on matter and motion?

The answer provided by Henninger-Voss in this section takes us to an intermediate setting: the library… in this case, the library of Galileo's one-eyed patron, Gian Vincenzo Pinelli. Radiating out from such a seemingly contemplative space was an active network of readers, writers and practitioners who shared a great interest in the problems of weaponry and ballistics and who sought to understand and control the course of technological, natural and socio-cultural developments. Galileo's genius has previously been presented in terms of his ability to mediate between the unique specificities of discrete material experiences – the actual firing of a cannon, for example – and the

[7] Galileo Galilei, *Operations of the geometric and military compass* (Washington D.C.: Smithsonian Institution Press, 1978), preface 'To the discerning reader'.

[8] Mattei Valleriani, 'A view on Galileo's *Ricordi autografi*. Galileo practitioner in Padua,' José Montesinos and Carlos Solis, eds., *Largo campo di filosofare. Eurosymposium Galileo 2001.* (La Orotava: Fundación Canaria Orotava de Historia de la Ciencia, 2001), pp. 281-291.

[9] Contrast Alexandre Koyré's words: 'Galileo did not learn his business from people who toiled in the arsenals and shipyards of Venice. Quite the contrary: he taught them *theirs*'. in his 'Galileo and Plato,' *Journal of the history of ideas*, IV (1943), p. 401 with Salviati's opening remarks from Day One of the *Discourse*. See Stillman Drake, ed., *Two new sciences: including centers of gravity and force of percussion* (Madison: University of Wisconsin Press, 1974), p. 11. For an interesting discussion, see Jürgen Renn and Matteo Valleriani, 'Galileo and the challenge of the Arsenal,' *Nuncius* 16 (2001): 481-503. See also Simon Schaffer's essay in this volume.

abstract world of philosophical reflection, using the tools of mathematics and literary representation.[10] Focusing on his *Dialogue concerning two chief world systems*, however, Henninger Voss shows that he did more than employ these tools to transmute the practical know-how of military engineers, bombardiers and artillerymen into a means to understand material motion in general. Galileo simultaneously proffered his book as an instruction manual that taught his audience the proper way to read technical information, natural philosophical texts *and* the book of nature. Material and knowledge production alike, he demonstrated, involve acts of reading. As with any other skill, one must either learn to read properly and effectively (as defined by Galileo), or risk producing a deficient product. Poor reading habits led to arid philosophy in the library, faulty design in the workshop and death on the battlefield.

While Galileo was gaining and translating experience in the shadow of the Thirty Year's War, a young René Descartes set off to see the world as a gentleman soldier, successively serving as an officer under Prince Maurits in Holland (1617), the Duke of Bavaria (to fight against Frederick V, Elector Palatine and King of Bohemia, 1619) and as part of the Imperial army's Hungarian campaign (1621).[11] Though Descartes was enormously unforthcoming regarding significant details of his autobiography, we know that he spent much of his time in the Netherlands campaigning with Isaac Beeckman and others to understand the mechanical structure of nature rather than worrying about troop deployments. And it was while wintering in Ulm (home of Johann Faulhaber's school for mathematics and military engineering) with the Duke of Bavaria's army that he first dreamed of uniting philosophy with wisdom.

Taking up 'the great book of the world,' as Descartes put it, and 'holding intercourse with men of different dispositions and ranks' certainly served him and the future history of philosophy well.[12] By focusing especially on Descartes' interests and activities related to the field of dioptrics, Fokko Jan Dijksterhuis reveals in his essay just how intimate such intercourse could be as Descartes and his collaborators ('men of different dispositions and ranks') *together* ground lenses and gained insight. Theirs was not an instance of what we might call inter-disciplinary co-operation, however, where each member contributed a single type of knowledge or skill. Rather, a hybrid form of activity that married manipulation and contemplation marked their close collaboration.

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[10] Peter Dear, *Discipline and experience: the mathematical way in the Scientific Revolution* (Chicago: University of Chicago Press, 1995), pp. 124-129.

[11] For the impact of the war on Galileo's relationship with Rome, see Pietro Redondi, *Galileo heretic* (Princeton: Princeton University Press, 1987), pp. 231-232.

[12] René Descartes, *Discours de la méthode* (Leiden, 1637), Part I.

Indeed, and this is Dijksterhuis' larger argument, early modern mathematics generally needs to be reconsidered as a hybrid field in which 'contemplation and manipulation are almost completely interwoven'. Distinctions that did exist between various forms of mathematical practice were social, cultural and goal-oriented rather than essential. Hence, whether in the hands (and mind) of the aristocratic Christiaan Huygens or the draughtsman Claude Mydorge, tinkering with lenses ground from glass or circles drawn on paper advanced the construction of both instruments *and* theory. And yet, Huygens' father took umbrage at his son being called a *mathématicien*, which he took to indicate the rank of a craftsman. In keeping with his social and cultural status, Huygens, like Descartes and all those who aspired to cultural respectability, preferred the title of (natural) philosopher. But, by retrospectively reading such labels as indicative of essential distinctions and a superior status for theory over practice – what we might call the Platonization of early modern history – we arrive at a false and bifurcated image of mathematization as, on one hand, the idealising method whereby philosophers mechanised the world-picture and, on the other, an applied set of practices whereby mechanics improved their techniques and tools. As Dijksterhuis explains, early modern mathematics is much better understood as involving the circulation of practices among various social, institutional, craft and knowledge domains. To quote him, 'the creativity of introducing mathematical practices in new domains then consists of ingeniously appropriating tools and methods developed elsewhere'.

Set between the essays by Henninger Voss and Dijksterhuis, Pamela Smith focuses explicitly on artisans as knowledge-makers. Thanks to the broad readership achieved by her recent book *The body of the artisan*, it is not necessary to rehearse her general argument here. What is of special note is the particular attention she gives to goldsmiths in her essay. Thus far, the omnipresence of war as a backdrop to the historical period covered by this section has served as a vehicle for introducing the issues taken up here. Should we be surprised to find that Renaissance and early modern goldsmiths engaged in a broad variety of activities, including gun and cannon casting, or to note that some, including Benvenuto Cellini, engaged in multiple professions, working as goldsmiths *and* military engineers?

Goldsmiths were masters of exquisite techniques that demanded both manual and arithmetic exactitude. Some were also authors whose treatises bear witness to the hybrid character of their careers. Lorenzo Ghiberti, for example, left posterity both the doors of the Florentine baptistery referred to by Michelangelo as the 'gates of paradise' and a learned treatise on sculpture. Strikingly, he began his *Commentarii* with an excerpt from an ancient Greek text on siege machines. Cellini, well-known because of his willingness to record the song of his own praise, apparently found the mechanical aspects of writing so tedious that he hired an assistant to transcribe his *Autobiography*, which he dictated while sculpting a marble crucifix. He clearly found no dishonour in working with his hands, so long as the results directly manifested his genius.

Indeed, Cellini wrote in his treatise *On Goldsmithing*, 'I consider that practice always has come before theory in every discipline (*tutte le scienzie*), and that rules of theory, in which your skilful craftsman is accomplished, are always grafted on to practice afterwards'.[13] The work of any master, we might conclude, involved a fusion of trained bodily movements and the expression of genius. This was the 'practice' to which Cellini opposed theory; a hybrid of deliberate and spontaneous work contrasted with *post facto* reflection. Such a view does not map any easier onto a division between the work of thoughtful mind and dumb hand, than it does onto later conceptions of superior theory and dependent practice. Rather it reminds us of the complex entanglements of head and hand that marked *tutte le scienzie* explored in this book, both in terms of the work done by individuals and that which involved group co-operation. Smith relates this mangle in her essay to the term 'distributed cognition'. We might instead want to entertain an expression that captures a more complicated and hybrid process – one too productively active to be either practically or teleologically circumscribed by 'cognition'. [14]

We are reminded further of how important it is that we attend to the ways in which the entanglements of head and hand were subsequently sorted out, their components assigned for various reasons to historically vexed and vexing categories that retrospectively ascribed labels and values to individual participants and their contributions. As Dijksterhuis notes in his essay, status clearly mattered to historical actors and terms such as philosophy and theory exuded the gleam of cultural capital. In the right hands, they could also be translated into socio-economic capital, enriching and ennobling some at the expense of others. Our task, then, is double. We need to recover the primacy of head-hand hybridity and make sense of the post-hoc classifications that came to take on the patina of essential truth. [15]

Renaissance goldsmiths are of interest here for yet another reason, situated as their activities were within complexly evolving economies of commerce and patronage.[16] We might set the goods they produced alongside the technological activities of Renaissance engineers such as Leonardo da Vinci in terms of their

[13] Pamela Long, *Openness, secrecy, authorship: technical arts and the culture of knowledge from Antiquity to the Renaissance* (Baltimore: Johns Hopkins University Press, 2001), pp. 132, 238-239.

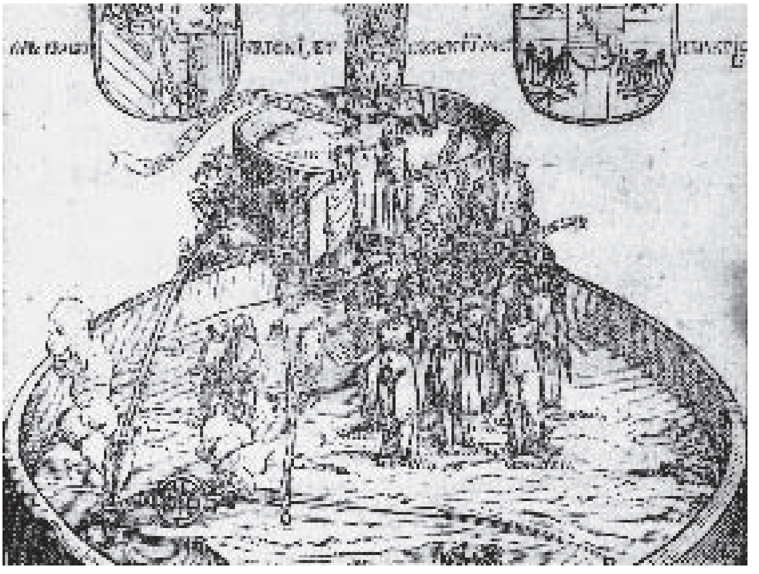
[14] For the concept of 'distributed cognition' see Pamela Smith's essay in this section and Edwin Hutchins, *Cognition in the wild* (Cambridge: MIT Press, 1995).

[15] For a current critique of the reification of categories, see Sheila Jasanoff, *The co-production of science and social order* (London: Routledge, 2004).

[16] Pamela Smith and Paula Findlen, eds., *Merchants and marvels*.

all having been part of a regime of wealth-consumption predominantly overseen by courtly patrons. As Thomas Misa relates in his recent textbook *Leonardo to the Internet*, technology, politics and culture were never far apart in the courts and city-states of Renaissance Europe. The technical projects and artisanal products commissioned there – ranging from stunning cathedrals and ferocious weaponry to printed books and theatrical automata – simultaneously helped create and constituted Renaissance culture. Patron demand for urban development, conspicuous courtly display, emblems of dynastic pretension and innovative tools for waging war fed a system that produced knowledge and goods as it consumed vast resources and talent. This reminds us that the 'mindful hand' was no disembodied actor. What shaped the historical contours of its productive activities were the very socio-political contexts it helped to build.[17]

[17] Thomas J. Misa, *Leonardo to the Internet: technology and culture from the Renaissance to the present* (Baltimore: Johns Hopkins University Press, 2004), chapter one: 'Technologies of the court, 1450-1600'. In his second chapter, Misa turns his focus from the wealth-consuming culture directed by Renaissance patrons to the 'techniques of commerce' that married technology to the culture of Dutch capitalism during the long seventeenth century. While it is beyond the scope of this introduction, it would be interesting to examine whether Misa's portrayal of the techno-cultural matrix that characterized Dutch urban society in the seventeenth century can help make sense of how aspects of the so-called mechanical philosophy involving figures such as Descartes, Huygens and Beeckman developed as they did.



GianVincenzo Pinelli collected works ranging from comet observations, such as this image of the comet of 1577 by Jiri Daschitzky from a German news sheet, to technical works, such as the bombardiering science of Nicolò Tartaglia, as depicted here in the frontispiece to his *Nova Scientia*. Those in Pinelli's circle were interested in mapping both the motions of heavenly bodies and the trajectories of cannonballs, but offered particular ways of reading such phenomena.

ILLUSTRATION 1

Comets and cannonballs: reading technology in a sixteenth-century library

Mary Henninger-Voss

The Cinquecento library was a place where miniature representations of the outside world – globes, armillary spheres, natural history cabinets, and model machines – were set beside the texts that informed the age. The great libraries were usually the collections of aristocrats and princes, men steeped in a broad humanist education and engaged in the affairs of state. Here mingled the philosophical treatise, the technical artefact and, increasingly, the technical handbook. In the library of the Paduan bibliophile GianVincenzo Pinelli, that intermingling could become intimate. Pinelli entertained a wide array of patricians and scholars whose preoccupation to understand and control the world of technology with its ships, arsenals and mills shaped many of their encounters with texts and ideas. Their efforts to understand and control technologies such as gunpowder weapons took place largely by trying to translate technical processes into texts, and translate texts into objects through technical expertise, whether their own or others'. A process of reading accompanied this effort, and *as* reading, knowledge of technical processes could be aligned with, or challenge, traditional philosophical knowledge. The social alliance of the men who frequented Pinelli's library gave rise to intellectual alliances that stretched from the most mundane of technical problems to the most speculative of philosophical discourse. The divergent interests of such social alliances were papered over, literally, through the circulation of information, expertise, and books.

If the early modern period displays a vast reorientation of natural philosophers to technical processes, the period also demonstrates their complete reconsideration of the role of books in the natural philosopher's method. Galileo's own brilliant polemic in *Dialogue concerning the two chief world systems* etched the figure of the book-bound pedant in sharp relief to the new-style natural philosopher. If historians of science have in large part rejected the iconic force this picture sometimes has fostered – that of a theory-laden scholar blind to the rational investigation of an unprejudiced, empirically-based scientist – our attention has nevertheless most often been directed to the ways in which early modern thinkers appreciated or appropriated technical and practical information.

However, what I am interested in here is not the ways in which the technical were subsumed into natural philosophical accounts, but a first investigation into how technical accounts, experiences, and literature were digested in the assumptions and reading practices of elite groups in early modern Italy. Galileo warned, 'Our discourses must relate to the sensible world and not the one on paper,' but of course he himself was presenting us with a world on paper, the veracity of which the reader was expected to judge.[1]

I will here examine the reading practices around Gian Vincenzo Pinelli in respect to technical subjects, but particularly in respect to questions of artillery shot – questions which could pertain to subjects as disparate as calculating instruments and comets. Pinelli's library in Padua was the centre of a large circle (or circles) of readers, and his correspondence displays the trajectory of technical knowledge as it passed through Pinelli's sphere of peers and pundits. In the work of Pinelli's client, Galileo, technical knowledge, a style of reading, and an expectation of book knowledge came together in the form of Galileo's argument in *Dialogue concerning the two chief world systems*.

Circuits of readers

In the summer of 1580, the artillery general Giulio Savorgnano wrote to Gian Vincenzo Pinelli, thanking him for the objects and writings Pinelli had sent: some metal wheels (for pulling a weight 'worthy of Archimedes'), a comedy, and a writing on the borders of the Turkish empire. In his letter, Savorgnano appreciated the comedy, but also recognised Pinelli's sensitivity to his own interests in machines and the on-going wars with the Turks. Savorgnano also invited Pinelli to Osopo, his fortress-home in the Friuli. Savorgnano prided his estate for its experimental lifting and shooting machines, and told Pinelli that Osopo offered walls 'stronger than Arichimedes might have built,' not only for keeping out the Germans, but also the plague. 'I offer it, a house designed for anything, and the freedom to study, walk and live as you like without having to pay court to anyone'.[2] Despite vastly different orientations – Savorgnano toward warfare and Pinelli toward study – there was much to exchange between the households.

It is important to realise that Pinelli's household was not wholly different in kind from those belonging to many of his correspondents. Not only Savorgnano, but also Guidobaldo del Monte and the Venetian patrician Giacomo

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[1] Galileo Galilei, *Dialogue concerning the two chief world systems* (Berkeley: University of California Press, 1967), p. 113.

[2] Giulio Savorgnano to Giovan Vincenzo Pinelli, 8 June 1580, *Biblioteca Ambrosiana* [hereafter, Ambr.], R121 sup., 11r-12r.

Contarini considered their homes to be potential centres of philosophical discourse.[3] However, Pinelli bears particular consideration for the influence he wielded, both as a patron and as a model of patronage. Pinelli's house provided an important context for Galileo's work during his first nine years in Padua, and Pinelli was the figure on whom other aristocrats modelled their own philosophical commerce–notably the Venetian Antonio Querengo who took on many of Pinelli's local clients after the death of Pinelli, and Nicolas-Claude Fabri de Peiresc, who became the devoted patron of experimental natural philosophy in France.[4]

As Pinelli had a number of interests, he associated with a number of circles, many of them intersecting. Natural history, mathematics, religion, medicine, and ancient and contemporary literature were all subjects on which Pinelli carried on regular correspondence. I have marked out (rather artificially) a group of men interested in technological matters. This group includes the aristocrats Contarini, del Monte, Savorgnano, Alvise Mocenigo, and Francesco Barozzi – all of whom were either leaders deeply concerned with directing military affairs, mathematicians, or both. It also includes the university mathematicians Giuseppe Moletti and his successor, Galileo, as well as Pinelli's tireless intelligencer, Filippo Pigafetta, and possibly the theologian Paolo Sarpi. This list is by far neither complete nor isolated. For example, Galileo benefited not only from the interest of a powerful Venetian patrician like Contarini, but connection to the Medical professor Girolamo Mercuriale. At Pinelli's house Galileo made contacts to distant magnates such as Mark Welser, and most likely studied neo-stoic philosophy under Lipsius's influence. He harshly criticised the literary work of Pinelli's client, Torquato Tasso, and clashed with a group of alchemically-inclined scholars.[5]

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[3] For an instance of Guidobaldo del Monte's invitation for philosophical visits at his own home, see del Monte to Pier Matteo Giordani, 10 August 1588, *Biblioteca Oliveriana*, Ms. 426, cc159-160. For Contarini's estimation of his library as his most precious possession, see Manuscripts of G. Morelli, *Biblioteca Nazionale Marciana* (BNM), Ms. Riserv. 76. For a full description of Contarini's library, see Paul Lawrence Rose, 'Jacomo Contarini (1536-1595), a Venetian patron and collector of mathematical instruments,' *Physis* 18(1976):117-130.

[4] On Querengo, see Antonio Favaro, *Galileo Galilei e lo Studio di Padova*, vol. II, (Padua: Antenore, 1966), p. 59ff; on Peiresc, Pinelli's 'spiritual heir,' see Lisa T. Sarasohn, 'Nicolas-Claude Fabri de Peiresc and the patronage of the new science in the seventeenth century,' *Isis* 84 (1993): 70-90. More general discussions of the locus of a gentleman's house and the comportment and sort of knowledge produced there are available in Paula Findlen, *Possessing nature* (Berkeley, Los Angeles, London: University of California Press, 1994) and, for England, Steven Shapin, 'The house of experiment in seventeenth-century England', *Isis* 79 (1988): 373-404.

[5] Manfredo Tafuri also looks at this circle of men in 'Scienza, Politica e Architettura,' *Venezia e il Rinascimento* (Turin: Einaudi, 1985). References to Pinelli and others in his circle are frequently noted in passing in the vast literature on Galileo, including a number of studies on the relationship between Paolo Sarpi and Galileo. Of particular interest to this material: on Galileo's interaction with the circle

Pinelli's library was legendary even in his own day. Pinelli not only provided a rich library of printed books and rare manuscripts, but also collected minerals, metals, designs, globes, maps, mathematical and astronomical instruments, and botanical specimens. His collection of books may have been the most extensive and up-to-date of any in Italy. Already in 1627, Gabriel Naudé, who went on to become librarian to Cardinals Richelieu and Mazarin, recommended reading the 'Life of Pinelli' as part of a preparation for collecting a great library. Certainly Pinelli's correspondence centres on the texts he hoped to procure, have printed, or learn from.[6]

The most striking aspect of his collecting, however, is the extent to which he employed professional readers to buy and evaluate books.[7] Pinelli's agents fanned Europe. They bought both books that Pinelli had specifically asked for, and books they believed would be of interest. Pinelli probably read a good number of the well over 7,000 books and manuscripts that he collected, but for the most part, he was willing to employ others to read them for him. Moletti, for example, often submitted his opinions on works of mathematics, cosmography, and astronomy; in one missive he noted, 'If I buy candles for myself, [it is] to see so as to learn something for you'.[8]

Many of Pinelli's regular correspondents wrote him with specific information on new books. Girolamo Mercuriale, for example, wrote to apprise Pinelli of the contents of Patrizio's new work in which he had no other aim than to 'shame the philosophy of Aristotle'. Most often, however, Pinelli seems to have paid for opinions delivered orally and made with the book in hand. In a

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on the question of free fall and projectile motion, see Jürgen Renn, Peter Damerow, and Simone Rieger, 'Hunting the white elephant: when and how did Galileo discover the law of fall?' *Science in Context* 13(2000): 299-419; Stillman Drake gives some insight into the rivalries within the circle in the introduction to his translation of Galileo Galilei, *Operations of the geometric and military compass 1606* (Washington DC.: Smithsonian Institution Press, 1978). The suggestion that Galileo was drawn into a neo-stoic atmosphere in Pinelli's house is held by Eileen Reeves, *Painting the heavens: art and science in the age of Galileo* (Princeton University Press, 1997), and is drawn from the work of Peter Barker and R. Goldstein, 'Is seventeenth-century physics indebted to the Stoics?' *Centaurus* 27 (1984): 148-164.

[6] Information on Pinelli, his collection, and some correspondents can be found in Adolfo Rivolta, *Catalogo dei Codici Pinelliani dell'Ambrosiana* (Milan: Tipografia Arcivescovile S. Giuseppe, 1933) and, especially for his interests in Greek literature, Marcella Grendler, 'A Greek collection in Padua: the library of Gian Vincenzo Pinelli (1535-1601),' *Renaissance Quarterly* 33 (1980): 386-416. Gabriel Naudé, *Advice on establishing a library*, Archer Taylor, ed. (Berkeley and Los Angeles: University of California Press, 1950), p.11.

[7] The concept of the 'professional reader' was outlined in A. Grafton and L. Jardine, '"Studied for action": how Gabriel Harvey read his Livy,' *Past and Present* 129(1990): 30-78.

[8] Ambr. S105, f. 29.

long intimate letter to a friend, Pinelli warned that a commission must be paid to a certain consultant with perspicuity. 'We need to think about buying words by the weight,' Pinelli instructed. He offered a recent example in which a scholar came to his house, barely glanced at the book, answered no questions and gave no disputation, yet whose terse opinion Pinelli thought worth 10 ducats.[9]

The use of expert information was important to Pinelli, and he took care to match texts and experts, routing his sundry acquisitions through appropriate networks of professors and scholars. This is evident also in the editions Pinelli fostered. Pinelli took great care in collating the most complete extant text of Pappus's *Mathematical collections*, and had it translated and edited for the press by the most prominent mathematicians in northern Italy.[10] Pinelli also had his own clients working on the production of new texts. He set Moletti, his expert in mathematical sciences, to work with Pigafetta, who acted as his private war correspondent, to produce a work on ancient naval operations. After the mathematician Giovambattista della Porta visited in the early 1580s, Pinelli asked one of his experts in Rome to look over a manuscript of Apollonius which Porta had 'improved' in order to know 'if we have something to expect of it'.[11] Whether or not he himself was a polymath, Pinelli's taste was not for polymathic scholars such as may have been attractive in the generation before, but for men whose talents and interests matched specific pet projects of his own.

What is perhaps not immediately obvious from these few examples is that there is a pattern to these printing projects: a fascination with the ways in which the novelties of his own world related to the world of letters. Pappus's *Mathematical collections*, for example, included one of the few ancient discussions of mechanics as a science, and was very influential on Guidobaldo's work for contemporary use, his *Book on mechanics* (*Mechanicorum Liber*). Pigafetta translated this at the behest of Savorgnano, but using the library of Pinelli to match vernacular terms to Guidobaldo's Latin. For their naval work, Pigafetta and Moletti searched for designs of the ancient quinquereme – a five-oared galley that had served as the inspiration for one of the most innovative (and

9 For correspondence from Mercuriale, see Ambr. Ms. S107sup, f. 125; Pinelli's advice is in Ambr. Ms. S106sup, f. 20.

10 Some of Pinelli's correspondence regarding the edition of Pappus are found in Ambr. Ms. S106, ff. 21-22, f. 65r. On this edition, see also P.L. Rose, 'A Venetian patron and mathematician of the sixteenth century: Francesco Barozzi (1537-1604),' *Studi Veneziani* 1(1977): 119-178.

11 The project Moletti and Pigafetta worked on ('Leone Imperatore') is discussed in Ambr. Ms. D34inf, ff. 41 and 47; for Pinelli on the Apollonius, see Ambr. Ms. S106sup, f. 48r. For a description of Moletti's life and works, and the translation of his unfinished manuscript on mechanics, see W.R. Laird, *The unfinished mechanics of Giuseppe Moletti* (Toronto, 2000).

controversial) ship designs pursued by the Venetian Arsenal in the sixteenth century. Della Porta's study of conic sections also pertained to invention, as he spent a good deal of time with Contarini at the Arsenal casting a parabolic mirror. Pinelli himself traded news on where to find the best maps of the new world and collected books on navigation; however, he repeatedly referred back to Ptolemy's ancient work.[12] In this ambition to rectify all modern and ancient knowledge, however, there was something afoot much more original than simply another humanist looking for lessons in the encyclopaedia of the past.

The method of questions

Pinelli kept voluminous notes regarding his reading. Ann Blair has explored how the widespread habit of keeping 'commonplace books' where bits of information were collected under various categories (or 'commonplaces') leant itself to an encyclopaedic science of collected factoids.[13] However, Pinelli's notes do not seem to fit into that mould. They may indeed constitute a 'waste book,' or the set of notes from which one could enter in bits under their appropriate category in another place, yet these notes do not really contain much 'information' or factoids at all. Instead, one finds in Pinelli's workbooks numerous reminders on various *opinions* on books (often from authors of other books), and a number of tasks. Many entries begin with 'look at…' or 'find out…' or '[this person or author] says…'. Far from tending toward a knowledge that was built of bits and pieces, these pages appear to be a 'to do' and 'to think about' list that was part of an effort to correct and verify texts such that a coherent knowledge of both books and the veracity of their claims

[12] On the influence of Pappus on Guidobaldo, and the Pigafetta translation, see M. Henninger-Voss, 'Noble mechanics and working machines: Guidobaldo del Monte and the translation of knowledge,' *Isis* 91 (2000): 233-259. Pigafetta's reference to the quinquereme is in Ambr. Ms. D34inf, f. 47. The five-oared quinquereme was re-designed in the early 1500s by another humanist of Greek letters, Vettor Fausto, and was actually fabricated in the Venetian Arsenal. For two very different estimations of the actual success of the quinquereme, see F.C. Lane, *Venetian ships and ship builders of the Renaissance*, chapter 3 (Baltimore, 1934), and E. Concina, *L'Arsenale della Repubblica di Venezia* (Milan, 1984), pp. 112-113, and idem, *Navis: L'umanesimo sul mare* (Turin,, 1990), *passim*; for the re-opened discussion of the quinquereme in Contarini's orbit see my forthcoming 'The Venetian Arsenal as a city of experiment'. For Pinelli's interest in maps of foreign continents, see Rivolta, p. LX and XLIII. The same pattern can be seen in non-technical subjects, such as Mercuriale's work on exercise workouts and Fabricius's ambitious work to re-perform and illustrate Aristotle's experiments on the development of the embryo. On Mercuriale's use of Greek texts, see Nancy G. Siraisi, 'History, antiquarianism, and medicine: the case of Girolamo Mercuriale,' *Journal of the History of Ideas* 64 (2003): 231-251.

[13] Ann Blair, 'Humanist methods in natural philosophy: the commonplace book,' *Journal of the History of Ideas* 53 (1992): 535-539.

could be constructed. These were, perhaps, the source of the many questions his correspondents answered in their letters. Pinelli's queries sometimes posed standard questions of philological information, but other times demanded technical information that was not always a simple matter of textual knowledge.[14]

Questions appear to all begin in texts, but they in fact do not all end there. On one sheet of his notebook, Pinelli asks for the 'difference in weight according to the heaviness (*peso, quanto alla gravezza*)' of gold, lead, iron, silver and wood. The strange double definition for weight and heaviness probably has to do with the fact that Pinelli was reading the books of Nicolò Tartaglia, a practical mathematician who had investigated specific weights and positional weights in his attempts to put artillery shooting on a mathematical and philosophical basis. Tartaglia had also distinguished between the simple weight of a cannon ball and its 'positional' heaviness according to where it was on a projectile trajectory, and supported this analysis with reference to the speed of weights as they turned on a balance. Indeed beneath the instruction to find these different weights, we find Pinelli's note 'Look at Tartaglia where [he speaks] of Jordanus and of Archimedes'. This is probably a reference to Tartaglia's discussion on this topic of positional heaviness where he mentions a slight discrepancy between the methods of the scholastic Jordanus Nemorius and certain demonstrations of Archimedes.[15] It is entirely in keeping with Pinelli to seize just on this question of discrepancy between texts, but interesting that he relates it obviously to an investigation of real weights.

Some pages later, an entry instructs, 'find out if it is true that artillery [shot] at [an elevation of] 45 degrees makes a greater circle [longer arc?] than one shot at the 5th point [of a bombardier's squadra, or 32 1/2 degrees] or under'. This is a clear reference to Tartaglia's major claim in his first book, that a cannon shoots farthest from a 45 degree elevation because the ball is projected farthest along a circular arc. In his demonstration of how to determine the

[14] The understanding of ancient technical texts had long required technical expertise. See for example Pamela O. Long, *Openness, secrecy and authorship: technical arts and the culture of knowledge from Antiquity to the Renaissance* (Baltimore: The Johns Hopkins University Press, 2001), pp. 222-234. For an early example of Galileo's attempt to recreate an invention of Hero, see Ambr. Ms. R104sup, f. 376.

[15] These notes are found on Ambr. Ms. H2inf, f. 47v. The discussion of cannonballs in their trajectory is in book one of Nicolò Tartaglia, *Quesiti et Inventioni* (Venice, 1546); the reference to Jordanus and Archimedes is in book eight of the same work, f. 93r-v. Tartaglia also published editions of Jordanus and Archimedes: *Jordani opusculum de Ponderositate* (Venice, 1565) and *Opera Archimedis Syracusani Philosophi et Mathematici Ingegnosissimi* (Venice, 1543). For a discussion of the confusion between 'weight' and 'heaviness,' see my 'How the "new science" of cannons shook up the Aristotelian cosmos,' *Journal of the History of Ideas* (2002): 371-397.

distance of a shot from the angle of a cannon's elevation, Tartaglia also had explained the construction and use of an instrument by which soldiers could easily measure distance to a target. (Tartaglia also took up the question of land measure again in a later book.) Below the entry on the cannonshot, Pinelli wrote 'Look at …Tartaglia [for] the different ways and different places in which to measure land with some sticks – and make something of it…'[16]

Whether Pinelli had in mind to find out such things as the effect of elevation on cannon range by shooting a gun himself, or whether he would avail himself to the broad literature on military engineering, is an open question. It is clear that there were demonstrations often taking place in his house, however, and that he was not reading Tartaglia alone. In 1581, Moletti wrote, 'If Your Lordship wants the Tartaglia, my servant has the key to my room, and the book is in the covered bookshelf'.[17] The circle around Pinelli read technical works quite frequently in these years, as Guidobaldo's work on mechanics was translated and studied, and Giacomo Contarini became ever more steeped in the challenges of the military governance of the state. Technical writing, however, posed different questions about the distance between text and experience. What was the relationship between what is (mathematically) true and what works operationally? How would technical knowledge be received into the system of coherent knowledge that books might represent?

Demonstrations and instruments

Near the end of his life, Pinelli was asked his opinion on the *Astronomical letters* of Tycho Brahe. He replied that 'If Your Lordship…could procure a note on the instruments made by that prince, I would be most obliged, because to these I give faith just as to those of Tycho I have some doubt. It appears that he puts forth too much and that he entertains [propositions] outside the manner of the appearances'.[18] This is not to show that the bibliophile was in fact a thoroughgoing empiricist, but that by 1599, Pinelli had become savvy about instruments and their role in connecting experience, representation and verbal or mathematical demonstrations. In the previous two decades, Moletti, then Galileo had conferred with Guidobaldo and Contarini on simple mechanics and on the construction of mathematical instruments for calculation and drafting.

Guidobaldo's work on mechanics had set a challenge for others in his circle. Contarini corresponded with him about the specifics of setting up pulleys to

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16 Pinelli's notes, Ambr. Ms. H2inf, f. 79r. Tartaglia's first book was *Nova Scientia* (Venice, 1537).

17 Ambr. Ms. S105 sup, f. 59r.

18 cited in Rivolta, p. LIV.

achieve promised effects, as he had tried to perform the demonstration himself so far without success. Also, Guidobaldo's claims regarding the balance had drawn criticism from some, as Pigafetta reported in his translation of Guidobaldo's *Book on mechanics*. Again, physical demonstration allayed doubts of those who could witness it. The instrument was specifically designed by Guidobaldo, and Pigafetta had seen it work 'in the hands of the illustrious Signor Gio. Vincenzo Pinelli'. Such demonstrations took on the function of being three-dimensional diagrams. Contarini himself had a number of small machines in his own library, and Pinelli collected mathematical instruments with Moletti's guidance.[19]

An invention that repeatedly drew the interest of this circle of friends and scholars was Fabrizio Mordente's reduction compass. Mordente's compass allowed its operator to divide circles or lines into equal parts and to draft scaled representations. It rested on points set on paper; the angle opening of the two arms kept constant ratio, and sliding cursors could be moved to set the arms at a desired proportion according to scales engraved along the sides. Since so many problems of practical mathematics were solved by finding proportionalities, often between quantities represented as lines, this was an exciting instrument. Guidobaldo designed an improved version himself, and Contarini enthusiastically praised it.[20]

It was perhaps a Mordente compass that Contarini possessed when he criticised an instrument design of Moletti's that promised to 'draw parallel lines to any [lines] seen, measure distances and put them into design'. Moletti had written instructions and mathematical demonstrations for an instrument that did not yet exist. Contarini found the invention overly abstract, and noted that the soldiers who would need to use such a compass were usually 'idiots' and unlikely to master its intricacies.[21] As a leader of military administration, Contarini had in mind for the large scale production of such instruments their use in reconnaissance and cannon aim. The Mordente compass, for example, specifically made possible the quick solution of the mathematical methods for

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[19] Guidobaldo del Monte, trans. Filippo Pigafetta, *Le Mechaniche*, (Venice, 1581), f. 28v; the letters between Guidobaldo and Contarini were transcribed in Antonio Favaro, 'Due Lettere Inedite di Guidobaldo del Monte a Giacomo Contarini,' in *Atti del Reale Istituto Veneto di Scienze, Lettere, ed Arti* LIX (1899-1900): 303-312. On Contarini's instruments, see Paul Lawrence Rose, 'Jacomo Contarini,' p. 122. Moletti reported a number of times what instruments he planned to buy for his own work, and sometimes offered to pick up an instrument for Pinelli. See for example Ambr. Ms. S105sup, ff. 48 and 53.

[20] Information on Mordente's compass and its exceptional interest in Pinelli's circle is in Paul Lawrence Rose, 'The origins of the proportional compass from Mordente to Galileo,' *Physis* X (1968): 53-67 and the introduction to Galileo Galilei, trans. Stillman Drake, *Operations of the geometric and military compass 1606* (Washington DC, 1978).

[21] The tract by Moletti is Ambr. Ms. A71inf, 24r-28v; Contarini's reply is A71inf, 23r-v.

handling cannon that Tartaglia had devised.[22] However, Contarini also owned more refined instruments.

Instruments that could capture on paper relations between objects were not only useful in the fast-paced art of war, but in the more contemplative science of astronomy. In 1580, Guidobaldo obtained from Contarini permission to 'embellish' his forthcoming *Problematum Astronomicorum* with descriptions of an instrument of Contarini's that measured angles down to seconds of arc. Contarini also collected the design of a geared astrolabe that had 'the same effect in the reduction of degrees of a circumference as did the general compass [in the reduction] of lines'. That is, it was able to capture in miniature the angles between stars, just as the compass could reproduce proportions between lines in the visual plane.[23]

The new reduction and proportional compasses, however, could not have generated much interest among patricians and aristocrats if it had not been for the manuals promoting and explaining their use. Mordente published a broadsheet illustrating and describing his compass in 1567, evidently at the encouragement of Moletti. He also provided the supporting software: the instructions and possible uses for the compass, in five published works. In 1593 Pinelli ordered Mordente's book on the compass in relation to the problem of squaring the circle, perhaps to have Galileo read it (Moletti had passed away in 1588). Meanwhile, Michele Coignet, a Flemish engineer, wrote an exposition on Mordente's compass, then published three works (two in Latin) that described his own invention of a proportional compass, the instrument which probably most inspired Galileo's invention.[24] Galileo in fact made almost no profit from the production of his geometrical and military compass as a commodity, but capitalised on the need for written instructions that would render the compass useful. The compass cost 35 lire, two-thirds of which went to the instrument maker; the tuition for lessons on how to use the compass cost 120 lire. This effectively kept the cost of obtaining the manual high until a pirated copy forced Galileo to publish it in 1606.[25] Even Tartaglia, a pioneer in the use of printed books as a medium for promoting his expert services, had

[22] Mordente specifically detailed application of the compass according to Tartaglia's theories according to Paul Lawrence Rose, 'Origins,' p. 59.

[23] Bodleian Canon Ital. Ms. 145, ff 46 to 47. This codex contains a great number of measuring devices (including a copy of Moletti's *Facil modo di tirar linee paralelle* [*Easy way to draw parallel lines*], and appears to date to the 1580s).

[24] Pinelli's exchange with his bookseller is quoted in Rivolta, p. LIII; all other information comes from Paul Lawrence Rose, 'Origins'.

[25] Galileo Galilei, *Operations*, pp. 22-25. An interesting treatment of the pirated instructions for the compass is in Mario Biagioli, 'Replication or monopoly? The economies of invention and discovery in Galileo's observations of 1610,' *Science in context* 13 (2000): 547-592.

sold instruments that were to be bought with his 1537 book, *Nova Scientia*. It is no wonder that Pinelli asked if he could get a hold of some fine instruments in order to judge Tycho's claims in *Astronomical letters*.

An obsession with measuring and calculating instruments was a pan-European phenomenon in the late sixteenth-century, and is certainly not specific to this small circle of men. Nor, as Paula Findlen and Jay Tribby have shown, is the examination of 'experience' in a room where books and objects were collected.[26] My point here is that these *ur*-inscription devices stirred expectations for the happy union of the world on paper and the physical world around us, and their methods could be equally applied to the arts of artillery and to the contemplation of the stars. Likewise, balances and small pulleys could be so finely constructed as to make them instruments not for fish-sellers and dock-workers, but readers of ancient mathematics. None of these inventions or refinements had much meaning, however, without books to indicate possible or real meanings and uses. Even if only as a technical manual, instruments had to be drawn back into the library.

Cannons as philosophical instruments

It is perhaps a stretch to call the cannon a philosophical instrument. Cannons, however, were certainly the machines with which the greatest number of quantified experiments were made in the sixteenth and early seventeenth century. They were probably also the category of machine about which the greatest number of manuals and discourses were written. In the course of the sixteenth century, the problems of calculating the most advantageous positions from which to shoot cannons, which depended on the relationship between the trajectory and impact of the cannonball, became conflated with the problem of understanding the acceleration of objects in free fall (Aristotelian 'natural motion'). However, there were so many other numerous details involved in the actual experiences with cannons that the path of the

[26] There is a vast sixteenth-century literature on measuring devices, and an almost equally vast secondary literature examining this and that instrument. For a good overall treatment of the primary literature up until the third quarter of the century, see Judith Bryce, 'Cosimo Bartoli's *Del Modo di Misurare le Distanze* (1564): a reappraisal of his sources,' *Annali del'Istituto e Museo di Storia della Scienza Firenze (1980)*: 19-33. For a good description of some of the instruments, see James Bennett, *The divided circle: a history of instruments for astronomy, navigation and surveying* (Oxford: Phaidon, 1987). On the 'experiences' of natural history conversation groups, see Paula Findlen, *Possessing nature*, chapter five and, especially in regard to the use of experiment as a tool for reading (although of a later time period), see Jay Tribby, 'Cooking (with) Clio and Cleo: eloquence and experiment in seventeenth-century Florence,' *Journal of the History of Ideas* 52 (1991): 417-439.

cannonball was only one question amid a welter of other considerations in the management of artillery.

Cannons had to inhabit a prominent place in the imagination of any early modern Europeans who lived in fortified cities, where people's houses were periodically destroyed to make way for walls and outworks, and hundreds of artillery pieces stood ready for defence. The difficulties of controlling these unwieldy guns, and of training bombardiers to achieve something like accuracy in their aim, weighed heavily on many state leaders. Military careers were a common choice for the younger sons of wealthy families, at least in Northern and Central Italy.[27] In cities like Venice where the patriciate was deeply involved in questions of defence, knowledge of ordnance and fortification was especially cultivated. State and military leaders constantly traded and sought out information on the manufacture, transportation and shooting of cannons.

This was no less the case in the circle around Pinelli. Contarini and Guidobaldo both produced discourses on fortification, and corresponded with Savorgnano on military matters.[28] Galileo of course taught full courses on military engineering, and wrote out two treatises on the subject. Pinelli himself wrote letters of recommendation verifying the qualifications of a young man as a fortifications expert, included notes on the claims of engineers among other political and military news in his notebooks, and appears to have been asked his opinion on fortifications by a prince.[29]

The availability of the cannon and its importance in the society made it a powerful iconic source as well as a temperamental machine on whose reliability city defences were often designed. Amongst Pinelli's papers, we see the cannon brought into discourse both as an object one manages, with very specific experiences associated with it, and as a resonant 'common experience'. That is, Pinelli's collection shows the extent to which experts examined every variation of size, weight, aim, and charge, but also instances in which some aspect of cannon shot could be appropriated to make a speculative argument unconnected with the use of cannons. It was unlikely in any case that technical interests and philosophical interests would remain strictly apart when both occupied the same people.

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[27] See Brian Pullan, 'The occupations and investments of the Venetian nobility in the middle and late sixteenth century' in J.R. Hale, ed., *Renaissance Venice* (Totowa, NJ, 1973) and Gregory Hanlon, 'The decline of a provincial military aristocracy: Siena 1560-1740,' *Past and Present* 155 (1997): 64-108.

[28] One of Contarini's discourses on fortifications, one that disagrees with an opinion of Savorgnano's is Ambr. Ms. A71inf, ff. 30r-36r. On Guidobaldo's interest in fortifications, see Mary Henninger-Voss, 'Noble mechanics'.

[29] The recommendation is S106sup, f. 64r; The notebook is Ambr. Ms. I92inf, see esp. f. 22; the response addressed to 'Your Highness' is Ambr. Ms. S106sup, f. 69.

In written discourse, experience of bombardiers and captains was often entwined with precepts of natural philosophy as well as mathematical formulation. Pigafetta not only reported to Pinelli on troop movements and likely battle plans in his travels, but also gathered bits of military reason from men like Savorgnano who came up with simple mathematical rules and various tricks for shooting artillery.[30] This sort of information was often codified in more formal treatises, but there they invariably had to be compared to the claims of other authors on the topic, and invariably of Tartaglia. Whether or not an author agreed with Tartaglia's analyses as technically useful, they adopted his formulation of cannonball motion as a composite of natural and violent motion, and analysed the experience of cannon shot in the categories of Aristotelian philosophy.[31]

The *Dialogue* of Carlo Thieti is a handy example of the sixteenth-century artillery treatise, as Pinelli kept extensive notes on this dialogue among his papers. Like the reports and collections of Savorgnano, Thieti included both standard information and a vast number of tidbits and observations ranging from the shape of the barrel to the variable force of the gunpowder charges. Armed with experience, Thieti denied most of Tartaglia's specific claims, even as he completely adopted Tartaglia's terms and modes of analysis. Thieti rejected Tartaglia's main program, that one could find a rule through proportions to figure out how far a cannon will shoot, but his explanations were strangely abstract: Tartaglia, wrote Thieti, had reasoned not from surface to surface, according to experience, but from cubic to cubic quantities. Thieti maintained that the trajectory of a cannonball is only straight at the end, when it travels by natural motion alone.[32] Experience reigns throughout the text, yet the consideration of the phenomena in philosophical terms is inescapable.

Given the conflation of philosophical terms and cannonball motion, it should not be so surprising that we also find in Pinelli's collection a treatment on natural philosophical topics that engages the cannon as a key example in exactly the question of the nature of weight and natural motion, and the import of that definition to the universal system. An anonymous tract on a passage from Aristotle's *On the heavens* explicitly employed cannon shot to challenge Aristotelian element theory. According to Aristotle, the 'natural motion' of all objects was determined by the elements of composition, which in turn were associated with a universal cosmography. In this way, Aristotelian theory

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30 For examples, see Ambr. Ms. R125sup, 92ff and Ambr. Ms. D34inf, f. 19r.

31 See M. Henninger-Voss, 'How the science of cannon'.

32 The notes are Ambr. Ms. S85sup, 255ff.

could explain why heavy objects always dropped downwards, faster and faster, while vapour and fire rise: Heavy things would do so because they are composed of earthen or watery elements and seek their 'natural place' at the centre of the earth (the universal centre), while airy and fiery elements were light, and travelled upwards toward the moon. How, in such a scheme, can one account for the flight of a cannonball with its variable speed and strange effects of natural and forced motion?

The author begins by indicating a question that has been posed him: 'I believe you have in mind a passage from Aristotle's *Heavens*, and it is the third text which is most pertinent to mechanical matters'. The author goes on to question the meaning of Aristotle's terms 'forced motion' and the 'state [of motion]'. The cannonball trajectory calls into question Aristotle's analysis of motion, which cannot account for sidewise motion. The tract then offers an analysis of the trajectory in line with Tartaglia's 1546 formulation. The author claims that Aristotelian theories of motion based on the movements of elements directly toward or away from the centre cannot explain the motion of cannonball shots. By extension, the element theory cannot be trusted, nor its use in arguments about the inalterability of the heavens. 'Aristotle derived an infinite number of things seen to be true with experience (*esperienza)*, just as we experiment on them (*l'esperimentiamo*) every day; however, he said nothing of the cause and therefore I will believe that he was able to say little…'.[33]

This tract, in answer to a question posed on 'mechanical matters' in Aristotle's discussion of cosmography, confronts the Aristotelian text with the (new) everyday experiences of cannon. The essay is not cogent, but its very mediocrity testifies to the ways in which the problem of the cannonball's path easily entered into the imagination of the reader of philosophy – especially, perhaps, when reading for the gentry in charge of military matters. This is the trace of a rather enormous realisation that the peripheral phenomenon of projectile motion, filled with experience and endowed with importance primarily through the exigencies of cannon warfare, could unseat Aristotelian cosmography. There is no indication of the many specifics associated with cannonballs (or any other projectile), and no convincing analysis, but there is here the demand that natural philosophy be coherent with mechanical experience.

[33] Ambr. Ms. S107 sup, ff. 208r-211r. In fact, the tract is more complicated than here outlined, as it demands that Aristotle account not only for the shape of projectile motion, but for the known 'experience' that cannonballs are fastest in the middle of their motion. This was actually a common belief of artillery men.

Comets and cannonballs

There is one other notable use of the cannonball in a natural philosophical context among the papers that Pinelli collected on the new star of 1572 and the comet of 1577.[34] Baldassar Pisanelli's mention of the cannon in his treatise on the comet of 1577 is simultaneously casual and erudite. On the whole, the treatise is a wholly predictable conglomeration of exact measures of the comet's position, Aristotelian explanation and prognostications of the effects and significance of the comet. According to Aristotle, comets occurred because the hot exhalations which fill outer space are moved along by the spheres of the planets and fixed stars; sometimes the heat caused by this motion makes them catch fire, and these burning exhalations are what we see as comets. In order to make his readers understand this, Pisanelli compared the ignition of a comet to the way in which gunpowder for cannons ignites in very hot air before the match actually touches the powder. Strangely he follows this observation, 'And also we read how Medea, that famous enchantress and witch, burned a crown…'. By the Medea fable, we can see that fire is attracted to things that contain within them the seed of fire.[35] Obviously the reference to cannon here merely serves as an anecdotal illustration, a vehicle to convey Pisanelli's understanding of the process by which comets are ignited. As such, it may as well be a fable which also conveys understanding; in either case the lesson must be drawn out and revealed by reading into them the philosophical concepts of attraction and 'seed' of fire.

It is a revealing coincidence that over a half-century later, Horatio Grassi would employ the cannon in a different way for a similar purpose. Grassi's discourse on the comet of 1618 had been drubbed by one of Galileo's disciples, probably with Galileo's assistance. The Galilean, Mario Guiducci, had particularly criticised Grassi's adherence to the Aristotelian theory that comets were caused by the motion of hot exhalations. Guiducci maintained that not motion, but only *friction* causes heat. Grassi responded directly to Galileo: Not only Aristotle, but 'almost innumerable men of great name have presented examples of this [heat caused by motion] – undoubtedly from things which they themselves observed'. After enlisting stories from Ovid, Vergil and the historian Suidas, Grassi noted that a recent French writer described having witnessed how lead cannonballs had melted in flight, and became useless for

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[34] Ambr. Ms. R95sup. Half of this codex pertains to comets; the other half interestingly to religious war and fortification.

[35] Ambr. Ms. R95 sup, f. 42v. The work is a manuscript copy of Baldassar Pisanelli, *Discorso sopra quello che minaccia doverne avenire la comete apparsa questo anno 1577* (Florence, 1577). For information about stock ideas about comets, and the comet of 1577 in particular, see C. Doris Hellman*, The comet of 1577: its place in the history of astronomy* (Thesis, Columbia University, New York, 1944), also available from AMS Press (New York, 1971).

battery. To this, Grassi added his own observation of lead balls that had become acorn-shaped in their flight during battery, and claimed that daily examples of musket fire would also attest to the melting action of motion. This showed that the poet's descriptions of quick Balearic slingers whose lead balls melted in their slings, and the historian's account of Babylonians who cooked their eggs by whirling them very fast in a sling, could certainly be based on witnessed accounts, even if the events themselves were fortuitous and difficult to produce on demand. Clearly from experiments of all ages, we can conclude that 'leaden balls hurled from slings with great force would kindle the air by their motion, and in turn they would burn by that burning air'. From these examples, Grassi concluded, 'no refuge is permitted to Galileo' to deny that motion causes heat, and may ignite the air – as happens in comets.[36]

This was the sort of reading that drove Galileo to his most sarcastic extremes. What Grassi saw as the definitive collection of witnesses and facts of experience, Galileo would disarm as undigested hear-say and stray bits of eccentric observation. We may not have the poets at hand to verify their observations, Galileo noted in *The assayer*, but we do have slings and eggs and sturdy fellows to whirl them. Is it the quality of being Babylonian that causes a flying egg to heat instead of merely cool more? Further, Galileo knew of wax bullets that had penetrated unmelted through wood, and knew that a lead cannonball would not melt in a hot fire for some time. Could Grassi really expect us to believe that air around a cannonball could become much hotter than a furnace during the few seconds it was in flight rather than allow that air friction wore away the cannonball?[37]

Grassi was probably neither a bad mathematician nor a particularly bad experimentalist, but Galileo would portray him as a very bad reader. And worse, Grassi was in a prestigious position at the Jesuit Collegio Romano, and used his authority to support the astronomical views of Tycho Brahe. This was doubly condemnable since Brahe not only rejected Copernican astronomy with a jerry-rigged system to save the appearances of planetary motion, but that system made irrelevant any coherent theory of motion as regards centres of gravity.[38] In his later *Dialogue concerning the two world systems*, Galileo caricatured the pedantic reader, the credulous reader, the allegorical reader and the

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36 Horatio Grassi (under the pseudonym Lothario Sarsi), 'The astronomical balance', trans. C.D. O'Malley, *The controversy on the comets of 1618* (Philadelphia: University of Pennsylvania Press, 1960), pp. 117-121.

37 Galileo Galilei, *The assayer*, trans., Stillman Drake, *ibid*., pp. 297-299.

38 Peter Dear, *Discipline and experience* (Chicago and London: University of Chicago Press, 1995). The controversy over comets and new stars is much wider, more protracted, and tied into Galileo's Copernicanism than suggested here. See especially relevant parts of Eileen Reeves, *Painting the heavens*.

un-analytical reader all in the person of Simplicio; he also demonstrated what he believed was the philosopher's way of reading by teaching Simplicio to read his texts and his experiences.

In Book Two of *Dialogue concerning the two world systems*, Galileo successfully challenged Aristotelian philosophy largely from the vantage point of his experiences and investigations of artillery shot. In order to do so, however, he had to show the proper way to question both experience and books; the appropriate relationship between the world on paper and the world of real motions had to be demonstrated within the paper dialogue itself. The first section and final full third of Book Two portrays Galileo's representative, Salviati, reading books with Simplicio. Galileo himself never appears as a character in either of his published dialogues, but as an author whose work Salviati presents and explains. Salviati must show the reader how to move Galileo's philosophy out of the book in which it was encapsulated. He teaches the meaning of Galileo's analysis of projectiles apart from the context of technical treatises, and yet the style of reading is drawn from the reading of technical literature in a philosophical context.

Galileo's participation in Pinelli's circle had shaped Galileo's perception of the relationship of philosophy, technical knowledge and experience. These spheres had come together in the context of Pinelli's voracious and organised reading habits. The examination of a small snippet from Book Two will reveal the homologies between the style of reading that Galileo advocated in his popular dialogue, and the reading practices we have seen current in Pinelli's circle.

Galileo readings

The basic structure of Book Two is first to have Salviati examine and connect three phenomena that Aristotelians would be expected to enlist as support for a stationary earth: the free fall of a stone from a high tower, the fall of a stone from the mast of a ship and the shots of cannon, straight up and along the east-west line. (In each case, a traditional geocentric thinker would expect the projectile to land behind the mover if the earth itself were revolving underneath the projectile's flight.) Salviati will teach Simplicio how to re-read these experiences so that they in fact suggest the motion of the earth rather than deny it. One can understand projectiles as natural downward motion combined with violent transverse motion, and investigate analogous combined motions on the inclined plane. Indeed, Galileo's work with the inclined plane had been developed in his correspondence with members of the Pinelli circle, and had occupied Galileo for decades as a key to understanding parabolic motion.[39]

[39] The experiments were recorded in Guidobaldo's notebook, Bib. Nat. Paris Ms. 10246. A close account of the experiments with Galileo is Renn, Damerow, and Rieger, 'Hunting the white

In the *Dialogue*, Salviati denies the necessity to climb a tall mast of a moving ship in order to observe the combined effects of transverse and vertical motion by referring us to a thought experiment. Readers are instructed to imagine inclined planes with smooth mirror-like surfaces, down which a very hard, perfectly spherical bronze ball is rolled. We are to imagine the motion of the ball first in accelerated motion down a perpendicular plane, and then in the 'perpetual' (constant velocity) motion that a round frictionless ball would have on a perfectly level plane, given the tiniest impetus. Motion down a slanted plane, then, is intermediate between these motions and partakes of them both. But since what is perfectly level to us is actually the curved surface of the earth, the ball on 'flat' surface would be travelling in a circle about the centre of the earth. This now can be used to analyse the stone dropped from the ship's mast: the stone and the mast are travelling in a circle on the level ocean, equidistant from the centre of the earth; as the stone falls it does not resist the circular motion, but now is free to fall with accelerated motion to the deck below. Like the ball on the inclined plane, the ball falling from a mast would partake simultaneously of horizontal and vertical motions: the constant forward velocity of the ship and of the accelerated vertical motion due to gravity. The circular and straight motions do not interfere with each other. Likewise cannonball motion can be thought of as partaking in the circular motion of the earth, as if the earth were an enormous artillery carriage. Whether the cannon shoots straight up, or whether it shoots to the west or east, the ball will continue to partake of the circular motion.

The section has a rather ironic ending. Salviati calculates that the difference between a cannonball shot to the west assuming a stationary earth, and a cannonball shot to the west assuming an earth spinning diurnally to the east, would be approximately one inch. But, Salviati points out, the variation in the *same* shots, repeated at the same charge and aim, was about one yard. A short review of the technical discourse would tell us why: the distance of cannon shots varied according to the sphericity of the ball, the smoothness of the bore, the amount of the charge, the composition and grinding of the gunpowder, the material of the ball, the heat of the cannon and even the humidity of the air. Salviati turns to Simplicio: 'Don't you see that it is impossible to refute me without first finding a method of shooting with such precision at a mark that you never miss by a hairsbreadth?'[40]

elephant'. See also on this R.H. Naylor, 'Galileo's theory of projectile motion,' *Isis* 71 (1980): 550-570. Both Renn et.al. and Naylor are interested in the relationship of Galileo's inclined plane experiments to Galileo's law of free fall, fully articulated in the *Discourse on two new sciences*. Naylor actually denies that this work has anything to do with Copernicanism.

40 Galileo Galilei, *Dialogue*, p. 182.

Peter Dear has explored Galileo's reliance on reference to experiments performed many times over in contrast to the Jesuits' development of quantified notions of exact, discrete experiments.[41] It was perhaps Galileo's very awareness of the behemoth of technical details that led him away from casting any arguments from the point of view of this sort of discrete experience. As we see in the exchange between Salviati and Sagredo over the possibility of ever verifying earth's movement by firing a cannon in opposite directions, both the imprecision of military machines, and the tacit, even unconscious, practices of the men who fired them compromised their utility for philosophy, at least in an unmediated way. Galileo's strategy was to translate a problem that originated in a technical context to some analysable simple machine–the inclined plane or the balance, for example. These could be made into philosophical instruments, and treated mathematically. In a very self-conscious way, Galileo brought the cannon into the library (and with the *Discourse on two new sciences* he would bring the whole Arsenal). Technical knowledge was there re-fit for the requirements of philosophy, perhaps for the leisure of men normally assailed by the challenges of managing machines and men.

What did it mean to *do* philosophy for readers of *Dialogue*? Was the reader supposed to follow the author's footsteps and attempt to reveal nature's secrets? In fact, the characters seem to offer a particular transmission of philosophical knowledge: There are the new philosophers like Galileo 'our Academician' who can reveal in their demonstrations beautiful truths from the whole marble of experience; there are expert readers like Salviati who can judiciously evaluate and analyse demonstrations and texts (and readers like Simplicio who have developed only habits of collation and allegorical reading); and readers, like Sagredo, who could only be expected to be able to ask the right questions of experts like Salviati, and be able to judge the verisimilitude of their answers.

Conclusion

The title of this essay, 'Comets and cannonballs' is meant to draw attention first to the odd combination of these very different sorts of objects in the same space. They were in fact objects that very much shared professional space for the sort of mathematicians that both Moletti and Galileo were. These celestial and terrestrial projectiles also shared space as subjects on the bookshelves of Pinelli's library, and in the attention of the men who went there to read and converse. Pinelli provided a space for the technical knowledge the

[41] Peter Dear, *Discipline and experience*, pp. 124-150.

cannonball represents in a context where contemporary experience constantly confronted ancient knowledge. Reflecting the dilemma of printing over a century after its establishment, Pinelli employed expert readers to aide in his probes for coherent knowledge over an extremely wide field. Both Pinelli's collecting habits and his style of questioning hearken to an effort to bring the world on paper into verisimilitude with the world of the senses. This was further exemplified by the role demonstrations and experiments played in structuring experience and judging the efficacy of books.

Technical knowledge of artillery fit into this landscape, largely due to the need for such knowledge among state leaders. Fortuitously, artillery knowledge had already embedded philosophical and mathematical authors. An ambitious technical expert like Galileo could seize on the ways in which the proper reading of technical information could foil the reading habits of the prognosticators or the erudite that interpreted comets. In his own writing, Galileo presented his strategies born of military engineering questions, and fed by information from bombardiers and artillery men, as strategies for understanding the motion of all objects. He simultaneously provides his own reader with model methods of reading and judging natural philosophical demonstrations.

Acknowledgement

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Primary sources

Biblioteca Ambrosiana (Pinelli Collection).

Biblioteca Nazionale Marciana, Ms. Riserv. 76.

Biblioteca Oliveriana, Ms. 426.

Bibliothèque Nationale Paris, Ms. 10246.

Bodleian Library, Canon Ital. Ms. 145.

Galilei, Galileo, trans. Stillman Drake*, Operations of the geometric and military compass* (1606. Washington D.C.: Smithsonian Institution Press, 1978.).

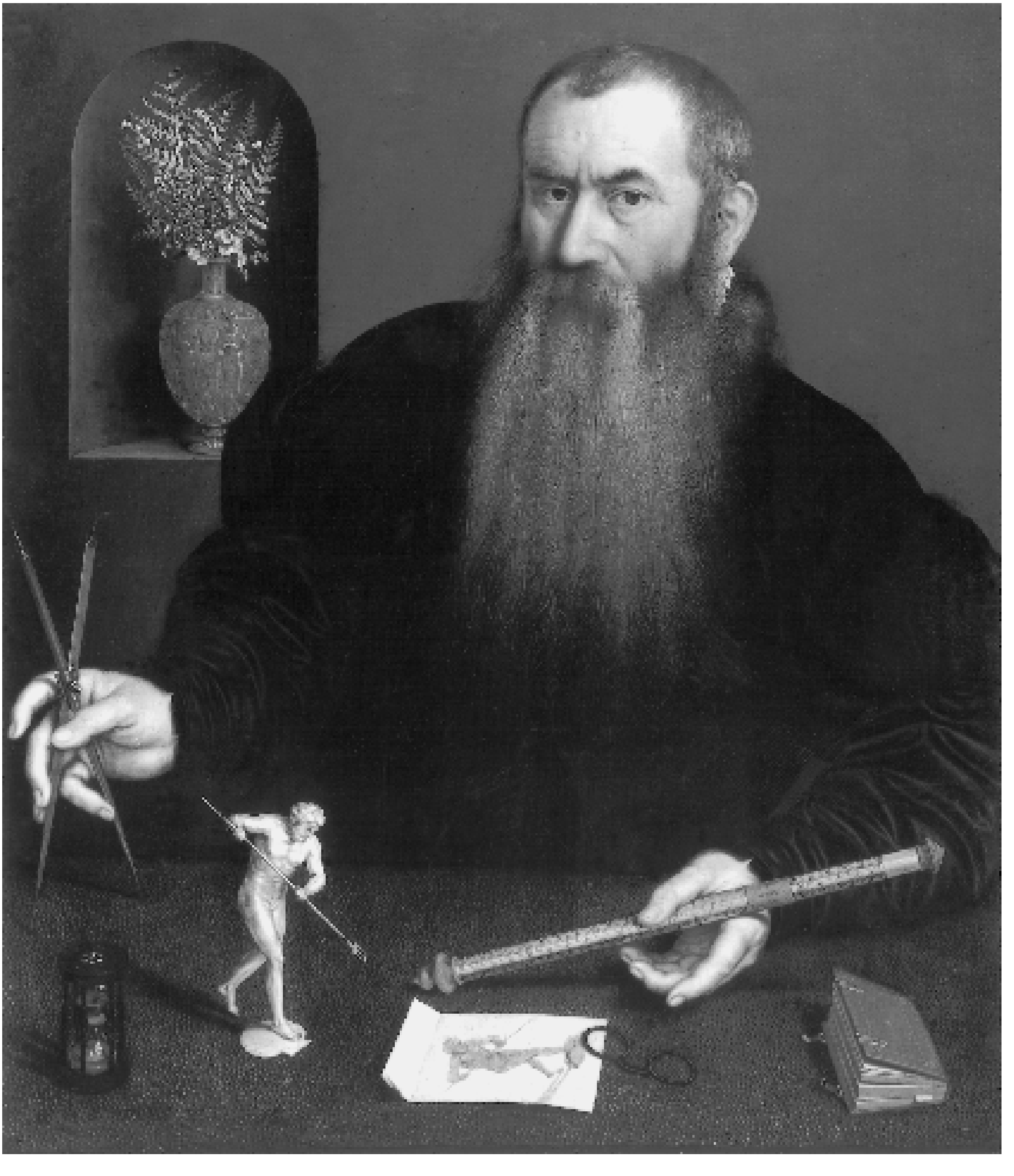
Galilei, Galileo, trans., Henry Crew and Alfonso de Salvio, *Discourse on two new sciences* (1638. New York: Dover, 1954).

Galilei, Galileo, trans., Stillman Drake, *Dialogue concerning the two chief world systems* (1632. Berkeley: University of California Press, 1967).

Galilei, Galileo, trans., Stillman Drake, 'The assayer,' *The controversy on the comets of 1618* (Philadelphia: University of Pennsylvania Press, 1960).

Grassi, Horatio (under the pseudonym Lothario Sarsi), trans. C.D.O'Malley, ' The astronomical balance,' *The controversy on the comets of 1618* (Philadelphia, University of Pennsylvania Press, 1960).

Monte, Guidobaldo Del, *Mechanicorum liber* (Pesaro, 1577).
Monte, Guidobaldo Del, trans. Filippo Pigafetta, *Le Mechaniche* (Venice, 1581).
Naudé, Gabriel, Archer Taylor, ed. *Advice on establishing a library* (Berkeley and Los Angeles: University of California Press, 1950).
Tartaglia, Nicolò *Nova Scientia* (Venice, 1537).
Tartaglia, Nicolò, *Jordani opusculum de Ponderositate* (Venice, 1565).
Tartaglia, Nicolò, *Opera Archimedis Syracusani Philosophi et Mathematici Ingegnosissimi* (Venice, 1543).



A map of ambition: Nicolas Neufchatel, *Portrait of Wenzel Jamnitzer*, c. 1562-1563, oil on canvas, 92 × 79 cm., Musée d'art et d'histoire, Geneva, inv. no. 1825-23, photo: J. M. Yersin.

ILLUSTRATION 2

In a sixteenth-century goldsmith's workshop

Pamela H. Smith

Craft and artisanal practice have come to assume a higher profile in the historiography of the scientific revolution in recent years, and most historians of science today would regard craftspeople as having an unspecified but significant place in the Scientific Revolution. But what actually went on in the workshop on a daily basis? What kinds of knowing were embodied in craft practices? What kinds of knowledge resulted from the production of objects? What can we say generally about the relations between hand and mind in and around artisanal workshops?

We usually think about the production of knowledge as resulting in a body of texts, but what kinds of knowledge result from the production of things? Those scholars whom we might expect to study the production of material things most intensively – art historians and historians of technology and science – have generally ignored the specifics of mechanics' and artisans' techniques. An admittedly dated anecdote about the art historian and collector, Bernard Berenson, tells us much about this neglect of the conditions and materials of making in art history. Bernard Berenson was asked at a trial dealing with the authenticity of works attributed to Leonardo da Vinci, 'you've given a good deal of study to the picture in the Louvre?' 'All my life' he replied, 'I've seen it a thousand times'. 'And is it on wood or canvas?' the interrogator asked. Berenson replied, 'I don't know,' and then quickly defended his answer with the remark that such details were of no consequence, 'it's as if you asked me on what kind of paper Shakespeare wrote his immortal sonnets'.[1] One could argue that it is in fact the paper and the print culture that paper fostered that *did* underlie Shakespeare's very existence as an author. But in a more significant counter to Berenson's ways of thinking about art, we must recognise

[1] Quoted in Molly Faries, 'Reshaping the field: the contribution of technical studies,' Maryan W. Ainsworth, ed., *Early Netherlandish painting at the crossroads. A critical look at current methodologies* (New Haven and London: Yale University Press, 2001), pp. 70-105, p. 84. The recent work of curators and conservators at the National Gallery, London, and the Metropolitan Museum, among other places, have done much to rectify the neglect of the material in art history.

that art (here understood as *ars* or mechanical art, not simply fine art) in the early modern period involved a marriage of manual skill and a particular form of knowledge. Moreover, it had as its end product objects that both demonstrated and constituted knowledge. Just as historians of the book have drawn our attention to texts as material objects whose production, identity and significance entailed a profoundly interactive relationship with knowledge, the products of the arts more generally demand similar treatment.[2]

Historians like Berenson were heirs to the intellectual and social stratification of the early modern period, in which artists became genius designers, scientists became genius theorisers and artisans became 'mere mechanics,' devoid of theorising capacities or of genius. The foremost editor of metalworking treatises, Cyril Stanley Smith, wrote about early modern metalworkers: 'The artisans were the true scientists of this period,' but 'they lacked the flash of genius to produce a consistent theoretical framework'.[3] In contrast to this view, I will argue that craft involved a way of knowing nature that was largely tacit and transmitted by social practices and institutions not generally recognised today as producing theoretical knowledge. This knowledge has an unfamiliar appearance to scholars because it is produced by bodily labour, rather than by words, and is often embodied in objects (and in artisans' practices), rather than in texts. In this essay, I examine craft as a process of making *and* knowing; that is, not solely a collection of techniques, but also a means by which a kind of theoretical knowledge is produced. Following a discussion of my claim, the second half of this essay presents a goldsmith's workshop in order to explore with more specificity the ways in which 'knowing' and 'doing' – the investigation of nature and craft practice – intersected in early modern Europe.

What are making and doing? What is craft knowledge?

If we attempt to draw up a taxonomy of knowledge, where does craft knowledge appear in it? We might use an Aristotelian hierarchy that places 'episteme' or 'scientia' – deductive knowledge contained in logical propositions or geometrical demonstrations – at the top. Below this would come practice or experience, a type of knowledge that deals in particulars and which is generalisable through the collection of individual cases and the processes of induction. Below this in the Aristotelian schema would stand techne, a how-to knowledge not generalisable in any way, partly because it deals with materials and specific

[2] On texts, see the essays in this volume by Adrian Johns and Mary Henninger-Voss; on instruments and other such objects, see the essays by Fokko Jan Dijksterhuis.

[3] Vannoccio Biringuccio, *The pirotechnia*, trans. by Cyril Stanley Smith and Martha Teach Gnudi (New York: Basic Books, 1943), Introduction by Cyril Stanley Smith, p. xiv.

instances and circumstances that are irregular and absolutely particular, and partly because the knowledge itself cannot be written down and transferred in texts from one person to another.

On the other hand, we might construct a different, but related, taxonomy that included, as one category, the Aristotelian knowledge of causes and, in a separate category, descriptive knowledge, such as natural history or chorography. Such Aristotelian taxonomies of knowledge very much influenced the epistemological worth and social standing of different kinds of knowledge and knowledge-makers throughout the pre-modern period in Europe (and arguably continue to influence us today). Recently, however, sociologists of knowledge have argued that allegedly tacit how-to knowledge can be generalisable and transferable if it is inscribed, perhaps not in a conventional text, but rather in a star map of, for example, Polynesian navigators, or in a template, by medieval cathedral builders, or in a quipu by Inca administrators.[4]

But is it possible to draw up an entirely different taxonomy, which considers the senses and the kind of knowledge people possess when they are experts of the hearing, smelling, touching or tasting? Wine connoisseurship, singing in harmony, the knowledge needed by early modern chemists to test the composition of materials by smell or taste all consist in knowledge of the senses. Artisanal manuals are full of directives about this type of discernment by listening, tasting and smelling. This type of knowledge is very hard to describe in words, but instead is known in the body.[5]

Finally, we might construct a taxonomy of knowledge that employs as categories various forms of embodiment, that is whether the knowledge can be expressed in symbols, in words, in texts or in objects. While I will not try to locate craft knowledge precisely in any of these taxonomies for the purposes of this essay, it is useful to consider alternative taxonomies of knowledge-making and knowledge-makers, for craft knowledge, in accord with the low status given it in the Aristotelian schema, has often been perceived as merely mechanical and learned by rote practice, rather than an ingredient or product of investigative practice. Along the same lines, it has been called inflexible, non creative, and unconcerned with precision.[6] With just a little study of the crafts, such stereotypes show themselves to be false. However, the problems of getting

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[4] Helen Watson-Verran and David Turnbull, 'Science and other indigenous knowledge systems,' Sheila Jasanoff, Gerald E. Marble, James C. Peterson and Trevor Pinch, eds., *Handbook of science and technology studies* (London: Sage Publications, 1995), pp. 115-139.

[5] In the case of chemistry, chemists attempted to organise such knowledge and teach it both through lectures and textbooks. See Lissa Roberts, 'The death of the sensuous chemist,' *Studies in the history and philosophy of science* 26 (1995): 503-29.

[6] See Peter Dormer, *The art of the maker: skill and its meaning in art, craft and design* (London: Thames and Hudson, 1994), pp. 8-10.

at craft knowledge – both that which is actively implicated in the production of material objects and that which derives from such processes and products – are real because it is often tacit, and historical sources are silent about it. So how do we go about building up a picture of the workshop as home to the hand *and* mind?

Sources for craft knowledge

The problem of getting at artisanal knowledge as an important element and product of workshop practices has been most fruitfully pursued by museum scholars in recent years. The sources they turn to for evidence include documents such as guild regulations, contracts, accounts, inventories, correspondence, descriptions of the workshop in written or pictorial form, artists' accounts and correspondence, and technical treatises.[7] Guild regulations tell us, for example, the precise thickness of wood to be used for panel painting (1470 statutes of Antwerp Guild of St. Luke), or that sculpture and panels could not be painted in a frost or in freezing conditions, unless the workshop was frost-free or heated.[8]

Such documents are records of practice, which has traditionally been regarded as a source of frustration. Records of practice seem no more than simple recipes that document a disordered and incoherent jumble of activities, moving from steel-making to digestive remedies on the same page. But what if we interpret the fact that these are records of practice to mean that we must study this kind of knowledge in the act of doing? Museum scholars have recently demonstrated how much can be learned about practice by technical analysis as well. For example, infrared reflectography reveals the underdrawings and design processes beneath the paint layers, while microscopy of paint samples can indicate the materials used. When one studies the layers of ground, underdrawing, and pigments, much is revealed about the techniques of production. In the case of sculpture, x-radiography of the sculpture can reveal techniques of fabrication, and chemical analysis of the metal alloys and core material can give additional information. When large scale testing of artworks is undertaken, such as the Getty Renaissance Bronze Project which seeks to subject as many Renaissance bronzes to technical laboratory analysis as possible, a great deal of information on practices of making is gained.

7 Lorne Campbell, Susan Foister and Ashok Roy, 'The methods and materials of Northern European painting, 1400-1550,' *National Gallery technical bulletin*, 18 (1997): 6-55, p. 7.
8 Ibid., p. 9.

The nature of artisanal knowledge

What emerges from research using both documents and technical analysis is twofold. First and most interestingly, it reveals the collaborative nature of artisanal production. Second, it reveals consistency in the patterns of material use and techniques of fabrication. For example, we know from documents that Rogier van der Weyden appears to have been employing more than one journeyman by 1434-35. Ten years later, he owned two adjacent properties near the Cantersteen in Brussels, one of which had an imposing entrance. It is obvious that he now possessed the space to organise a large team of assistants efficiently.[9] This much is taken from city documents. Technical analysis of five paintings taken from the thirty years of activity in Van der Weyden's workshop adds another dimension to this information. It indicates that the same materials were employed in all the paintings. Moreover these materials were used in the same ways. Indeed, certain basic techniques were clearly being taught in the workshop and passed from master to apprentice, such as the most successful pigment mixture to achieve a particular colour or the methods of building up modelling in draperies. The authors of this study conclude that, 'What distinguishes the paintings is the individual styles of the masters and the ways in which they, and their assistants, adapted these basic techniques'. The five pictures differ in the level of skill with which they were designed, drawn and painted, but analysis reveals that knowledge of technique was constant in the workshop during these thirty years of activity.[10]

Consistency of design could be achieved by the use of tools that served as reservoirs of collective cognition and knowledge, such as patterns, models and stencils, all included, for example, in the last will and testament drawn up by Bernadin Simondi in Aix-en-Provence in 1498.[11] The knowledge that made consistency in materials and techniques possible resided in such tools, but also in workshop practices and in the artisans themselves, and it was transmitted by means of observation, imitation and discussion from master to apprentice and from one journeyman to another. Benvenuto Cellini commented on the exchange of techniques and knowledge that happened in any workshop and over any complex piece of work when he noted of his time in Paris: 'I had in

9 Lorne Campbell, Susan Foister and Ashok Roy, 'The materials and technique of five paintings by Rogier van der Weyden and his workshop,' *National Gallery technical bulletin*, 18 (1997): 68-86, p. 68.

10 Ibid, p. 80.

11 Maryan W. Ainsworth, 'Commentary: an integrated approach,' Maryan W. Ainsworth, ed., *Early Netherlandish painting at the crossroads. A critical look at current methodologies* (New Haven and London: Yale University Press, 2001), pp. 106-121, p. 117.

my employ many workmen, and inasmuch as they very gladly learnt from me, so I was not above learning from them'.[12]

Sociologists and anthropologists label this form of learning 'legitimate peripheral participation'. Scholars of pedagogy believe this can be extremely effective because of 'the *situated* nature of learning, remembering and understanding' in general:[13]

> Traditionally, the study of cognitive processes, cognitive development, and the cultivation of educationally desirable skills and competencies has treated everything cognitive as being *possessed* and residing *in the heads* of individuals.... But once human behaviour is examined in real-life problem-solving situations and in other encounters with the social and technological surrounds, a rather different phenomenon emerges: People appear *to think in conjunction or partnership* with others and with the help of culturally provided tools and implements. Cognitions, it would seem, are not content-free tools that are brought to bear on this or that problem; rather, they emerge in a situation tackled by teams of people and the tools available to them.[14]

According to this model, cognition is distributed among a working group and situated in certain practices. Moreover, intelligence 'emerges' rather than being possessed.[15]

It is clear that in the early modern period, most artisanal work and the practical cognition that went along with it was undertaken by teams of people with their tools in a workshop setting. For example, in sixteenth century Nuremberg, the production of silver plaques that were to adorn the altar of the Sigismund chapel in the cathedral of Cracow was carried out in the following way. Peter Flötner carved models for goldsmiths to follow in boxwood or honestone (*Kehlheimer Stein*). Models were then cast in bronze by Pankraz Labenwolf and the patterns were passed on to the goldsmith Melchior Baier, to serve as a foundation upon which to emboss the silver plaques.[16] A similar example can be found in the collaboration on an ornate piece for a noble patron: a 1610

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[12] Benvenuto Cellini, *The two treatises on goldsmithing and sculpture,* trans. by C. R. Ashbee (New York: Dover, 1967), p. 84. Cellini's treatises contain numerous references to the conversations that went on in the workshop about techniques. The workshop could clearly be a place of intense 'technology transfer'.

[13] Jean Lave and Etienne Wenger, *Situated learning: legitimate peripheral participation* (Cambridge: Cambridge University Press, 1991), series foreword by Roy Pea and John Seely Brown, p. 11.

[14] Gavriel Salomon, ed., *Distributed cognitions. Psychological and educational considerations* (Cambridge: Cambridge University Press, 1993), series foreword by Roy Pea and John Seely Brown, p. xii.

[15] Ibid., p. xiv.

[16] J. F. Hayward, *Virtuoso goldsmiths and the triumph of mannerism, 1540-1620* (London: Sotheby Park Bernet Publications, 1976), p. 100.

letter from the Augsburg merchant Philipp Hainhofer to Duke Philipp of Pommern in December 1610 describes work on a silver sewing basket for the Duke:

> The woman Schwarz, who is plaiting the silver wire, Lencker doing a relief for the cover and 4 figures of eagles, Maulbrunn decorating the relief with gilt borders and precious stones; the woman Lotter making silver flowers, Gottfried Münderer casting insects and grasses from nature, Rigelstain [cold enamelling] the flowers, Achilles Langenbucher enamelling insects on the inside. Schwegler putting musk in a small box, Valti Michael enamelling the arms and fruit on the handle; Philip Froscher making the lock, Daniel Griesbeck carving the hard-stones, Milling making the straps.[17]

These are completely collaborative endeavours, and as a wonderful study by Michael Baxandall, in which he uses an account book to reconstruct workshop practices, makes clear, such collaborative projects also involved distributed cognition. The account book records the materials and payments made in connection with an altar generally ascribed to Hubert Gerhard made for the Fugger in Augsburg in 1581-82. Baxandall concludes that

> …metal sculpture is a co-operative thing. The altar bronzes were modelled by a young Italo-Netherlandish sculptor, the models translated into moulds by an experienced Florentine stuccateur, the moulds filled with great difficulty by a native copper-smith of Augsburg, the casts retrieved and worked up by a local goldsmith of not very great reputation. Gerhard's models were the basis for a cumulative development within the capacities of a succession of craftsmen.[18]

Such evidence of collaboration and collective problem-solving in the early modern workshop certainly goes against Romantic ideas about artists as individual geniuses and indicates just how anachronistic this concept of the individual genius 'artist' for the early modern period is.[19] Thus, we can add to our first point about craft requiring investigation 'in the act of doing' a second point about artisanal knowledge. It was collaborative and resulted in a body of techniques and knowledge that was transmitted in an integral and coherent way.

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[17] Quoted in Ibid., pp. 55-56. Such subcontracting was common among goldsmiths. Ibid., pp. 44-47 on Jamnitzer's subcontracting. Helen Clifford, '"The king's arms and feathers". A case study exploring the networks of manufacture operating in the London goldsmiths' trade in the eighteenth century,' David Mitchell, ed., *Goldsmiths, silversmiths and bankers: innovation and the transfer of skill 1550 to 1750.* Centre for Metropolitan History, working paper series, No. 2 (London: Alan Sutton Publishing Ltd. and Centre for Metropolitan History, 1995), pp. 84-95.

[18] Michael Baxandall, 'Hubert Gerhard and the altar of Christoph Fugger: the sculpture and its making,' *Münchner Jahrbuch der bildenden Kunst*, ser. 3, vol 17 (1966): 127-144, p. 134.

[19] Note that 'master craftsman' always possessed more layers of meaning than 'individual genius' – the appellation indicated that an individual had reached a certain social and intellectual level and status, as well as having attained a particular level of skill – he was an expert in his craft.

A third characteristic of craft knowledge was its marked public component. Craft knowledge was demonstrated in public. Artisans proved their mastery of a craft by producing a masterpiece, judged by the other guild members. In the early modern period when most artworks were made in accordance with a contract or sold on an emerging open art market, the proof was in the product. Often the contract included a clause that specified that 'good artists' would judge the final work before a maker could be paid the final instalment.[20] Isabella d'Este directed her agent Francesco Malatesta to consult Leonardo da Vinci about the value of some vases to be sold from the Medici collection.[21] The merchant and go-between, Philip Hainhofer, in writing to his princely patrons about works of art, assured them that the authenticity and value of works had been judged by knowledgeable artisans.[22] Craft knowledge obviously required the existence of a community of experts who discussed, compared and judged the artist's expertise (critics seem to fulfil this role for modern artists).[23] As Peter Dormer in *The art of the maker* expresses it, 'Public scrutiny is a key element in the development of tacit knowledge'.[24] Artisanal knowledge was demonstrated within a community of experts, and this demonstration was done by means of objects.

Let us pause for a moment to consider the picture I have laid out so far of the collaborative workshop. In the workshop, techniques were generated and knowledge emerged out of the process of making itself. In this dynamic process, knowledge was gained by doing; it was transmitted through observation

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[20] Allegra Presenti, 'Communicating design: drawings for the patron in Italy 1400-1600,' paper given at the V&A Seminar 3 February 2004. An example of artists assessing the work of their fellows is to be found in a 1480 document relating to Dieric Bouts from 1480, p. 13. A contract involving Michael Pacher states that if the finished work is not worth the contracted amount, each side will appoint equal numbers of experts, p. 78. On p. 60, a sixteenth-century contract states: 'They will make and complete for said city, as well as they are able, according to the standards of craftsmen and people who understand this matter, all and each of the works of painting and sculpture…' All three contracts contained in Wolfgang Stechow, *Northern Renaissance art 1400-1600: sources and documents* (Evanston, Ill.: Northwestern University Press, 1989).

[21] J. F. Hayward, *Virtuoso goldsmiths*, p. 77.

[22] Oscar Doering, 'Des Augburger Patriciers Philipp Hainhofer beziehungen zum Herzog Philipp II von Pommern-Stettin. Correspondenzen aus den jahren 1610-1619,' *Quellenschriften für Kunstgeschichte und Kunsttechnik des Mittelalters und der Neuzeit,* NF Bd. 6 (Vienna: Carl Graeser, 1894), pp. 74, 112.

[23] Rachel Laudan, 'Cognitive change in technology and science,' Rachel Laudan, ed., *The nature of technological knowledge. Are models of scientific change relevant?* (Dordrecht/Boston/Lancaster: D. Reidel Publishing Co., 1984), pp. 83-104, p. 94, makes the point that the community is the unit of technology transfer and the 'technology generator'.

[24] Peter Dormer, *The art of the maker*, p. 18. He notes that we test the language of craft against practice: '[I]f a metalworker says he can do this or that we ask him to demonstrate. Meanwhile, other knowledgeable people, metalworkers themselves, perhaps, would judge whether or not the work was 'good enough''.

and the imitation of bodily gestures; it was accumulated in and demonstrated by objects, which were judged and compared by experts. With this picture in mind, it is difficult to understand how craft knowledge came to have the reputation of being rote and mechanical. Indeed a process of continual problem solving that involved a disciplined body of knowledge and techniques that in turn disciplined the body seems to have been the order of the day.[25] But perhaps we can after all understand how this view of craft knowledge arose, when we realise the long years of training the body to perform certain actions. Such training required repetition and focus. Indeed every artist's manual records the constant replication of bodily practice necessary: The goldsmith and sculptor Cennino Cennini in the fourteenth-century, for example, wrote that the apprentice and journeyman must keep 'drawing all the time, never leaving off, either on holidays or on workdays'.[26] The painter Albrecht Dürer, son of a goldsmith, stressed the need for copying from one's master and from life.[27] Michelangelo too saw repetitious bodily practice as the key to knowledge; on a study sheet over some attempts by an apprentice, he scrawled: 'draw Antonio, draw Antonio/ draw and do not waste time'.[28]

For Dürer, art was dependent on the practices of imitation. The apprentice must first copy after a master and then after nature, resulting in a bodily storing up of experience. But Dürer emphasised that out of this bodily practice, 'art' – by which he meant a kind of knowledge that is larger than an individual's skills – comes into existence. Furthermore, these practices – transformed into art – are manifested in an object. In the 1520s, Dürer articulated the development of knowledge out of the seemingly rote practices of copying and drawing:

…never put it in thy head that thou couldst or wouldst make something better than God has empowered His created nature to produce. For thy might is powerless against the creation of God. Hence it follows that no man can ever make a beautiful image out of his private imagination [*eygen sinnen*] unless he have replenished his mind by

[25] Peter Dormer, ed., *The culture of craft: status and future* (Manchester: Manchester University Press, 1997), p. 17 puts it: 'Craft knowledge is generally disciplined knowledge, as disciplined as applied science. Craft knowledge also makes use of a concrete, precise verbal and written language. This language does not adequately describe the actual carrying out of a process because in any description of a practical activity too much that is important gets left out. Nonetheless, every craft has a technical language'.

[26] Cennino Cennini, *Il libro dell'arte (The craftsman's handbook)*, trans. by Daniel V. Thompson, Jr. (New York: Dover, 1960), pp. 64-65.

[27] See Pamela H. Smith, *The body of the artisan: art and experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004), p. 98.

[28] Carmen C. Bambach, *Drawing and painting in the Italian Renaissance workshop. Theory and practice, 1300-1600* (Cambridge: Cambridge University Press, 1999), p. 130.

much painting from life. That can no longer be called private but has become 'art' acquired and gained by study, which germinates, grows and becomes fruitful of its kind. Hence it comes that the stored-up secret treasure of the heart is manifested by the work and the new creature which a man creates in his heart in the shape of a thing.[29]

It is important to recognise that Dürer's practice of art resulted not only in his meticulous nature studies and his texts theorising artisanal practice, but also sparked a culture of nature study among artists, scholars and amateurs in Nuremberg and beyond. These practices of nature study, carried out by Dürer's students and apprentices are evident in the herbals of Hans Weiditz and Otto Brunfels and of Leonhart Fuchs of the 1530s and 40s.

This consideration of the practices of nature study among sixteenth-century German craftspeople reveals a fourth characteristic of artisanal knowledge: it was empirical, employing observation, precision and investigative experimentation. There is much evidence for the observing practices of craftspeople. Florike Egmond has provided an account of the *savoir prolétaire* of Adriaen Coenen (1514-87), a scribe to the fish auction clerk and a fish merchant in Schevening who kept a 'memory book' from 1530-87 of his observations on sea life. On the basis of this evidence, Egmond argues that 'lay' observers in the area of natural history were the sources of certain practices of observation and description; practices that were taken up by others at a higher social level in the course of the late sixteenth and seventeenth centuries.[30]

Early modern botanists recorded their exchanges with herb women, who gathered the herbs and informed the botanists of their names and usages. Even into the late eighteenth century, observing and making continued to be the expertise of artisans and practitioners. Similarly, Graham Hollister-Short has argued that the hundreds of thousands of machines built in early modern Europe must have had sophisticated and precise, but mostly tacit, numerical and mathematical measures because of the many different parameters that would have had to be mutually adjusted with every change in the overall dimensions of the machine. Builders of mills, war engines, pumps and other machines must have had rules of proportion by which they designed their machines.[31] Evidence of concern with measurement and precision can be found at every

[29] English translation by Erwin Panofsky, *The life and art of Albrecht Dürer* (Princeton: Princeton University Press: 1955), pp. 279-80.
[30] Florike Egmond, 'Natuurlijke historie en savoir prolétaire,' Florike Egmond, Eric Jorink and Rienk Vermij, eds., *Kometen, monsters en muilezels. Het veranderende natuurbeeld en de natuurwetenschap in de zeventiende eeuw* (Haarlem: Uitgeverij Arcadia, 1999), pp. 53-71.
[31] Graham Hollister-Short, 'Invisible technology, invisible numbers,' *Icon. Journal of the international committee for the history of technology* 1 (1995): 132-147.

turn. One has only to read Theophilus's account of bell-casting or Biringuccio's accounts of tempering steel to different hardnesses and of gun-making to realise the accuracy and expertise required by these crafts.[32]

The final important point about artisanal knowledge is its ability to respond flexibly in an environment that calls for far more than habit and rote responses. In describing blacksmithing, Charles and Janet Dixon Keller comment, 'Knowledge as organised for a particular task can never be sufficiently detailed, sufficiently precise, to anticipate exactly the conditions or results of actions. Action is never totally controlled by the actor but influenced by the vagaries of the physical and social world. Thus, in any given instance, knowledge is continually being refined, enriched, or completely revised by experience'.[33] This was as true for early modern artisanal knowledge as it is for modern blacksmiths. Artisans had to take account of weather (remember the example of the frost-free workshop with which I began), moment and impurities of material, among other factors. Artisanal knowledge was inherently particularistic; it necessitated playing off and employing the particularities of materials (including, in some cases, the impurities in the material).[34] Contrary to intuition, however, the particularistic nature of experiential knowledge did not preclude developing skills of generalisation and abstraction. Although such a development may be difficult to extrapolate from early modern sources, we can see such a development among modern artisans.[35] In a study of Liberian tailors trained by apprenticeship in the 1970s, Jean Lave found that a very high percentage of them could solve mathematical problems both within the 'embedded' context of their tailoring, for example, 'If the trousers were lying flat on the table and

[32] Vannoccio Biringuccio, *The pirotechnia*, ch. 11; Theophilus, *On divers arts*, trans. and introduced by John G. Hawthorne and Cyril Stanley Smith (New York: Dover Publications, 1979), pp. 167 ff.

[33] Charles Keller and Janet Dixon Keller, 'Thinking and acting with iron,' Seth Chaiklin and Jean Lave, eds., *Understanding practice: perspectives on activity and context* (Cambridge: Cambridge University Press, 1993), pp. 125-143, p. 127. The anthropologist Edwin Hutchins in *Cognition in the wild* discusses nautical navigation which he describes in great and persuasive detail as an example of distributed cognition, as a sort of knowledge that could not happen in just one person. But the point he makes that is relevant here is that the knowledge produced at any given moment is new because it is responding to the constantly changing circumstances of a ship at sea. Edwin Hutchins, *Cognition in the wild* (Cambridge: MIT Press, 1995).

[34] As in the example of iron gall ink recounted in Ernst Striebel, 'Über das färben von Holz, Horn und Bein. Das Augsburger kunstbuechlin von 1535,' *Restauro*, 6 (2003): 424-30; iron gall ink, p. 429.

[35] Although historians often hesitate to employ modern reconstruction of technique and to draw analogies with modern craft practices, it is important to remember that the methods for getting at tacit knowledge are more nearly analogous to archaeologists' reconstructions of prehistoric tools and techniques than to historians' use of archival documents. Such reconstruction is an accepted methodology in archaeology.

you measured the cuff as eight inches, what would it measure all the way around,'[36] as well as out of context as an abstract statement. Lave concludes that 'the inductive teaching/learning techniques of apprenticeship training do not prevent the formation of general problem-solving principles'.[37]

From this brief introduction, I think we can agree that artisanal knowledge had several characteristics: It was disciplined by years of practice, was precise, cumulative, experimental, investigative, demonstrated (visually and practically), collaborative and an example of distributed cognition. It was largely acquired through observation and imitation, rather than through texts, because written descriptions leave out too much information and would not develop flexibility in responding to always-changing environments. It responded to particular and fluid situations. It relied upon external demonstration within a public setting and was dependent on a community of practitioners. Finally, it resided in and was 'proven' by objects.[38]

In the rest of this essay I further specify this characterisation of artisanal knowledge by examining what took place in and around an early-modern goldsmith's workshop. This case study indicates that making was an investigative as well as a productive activity, and that the texts *and* objects of the goldsmith's workshop simultaneously demonstrated skill and investigative inquiry. Making and knowing intersected in the early modern workshop.

The goldsmith's workshop of Wenzel Jamnitzer

Compared to other crafts, goldsmithing left many traces in the documentary record. This is because goldsmiths were at the very top of the guild hierarchy in terms of their level of wealth, social status and the nobility of the people with whom they interacted, as well as the materials in which they trafficked. Goldsmiths left more records, were more often literate and have been studied in much greater detail by historians than, say, shoemakers. Goldsmith-sculptors such as Benvenuto Cellini left entire autobiographies in manuscript, while others such as Adriaen de Vries left autobiographical fragments in their sculptures themselves.[39]

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[36] Jean Lave, 'Cognitive consequences of traditional apprenticeship training in West Africa,' *Anthropology and education quarterly 8* (1977): 170-80, p. 178.

[37] Ibid., p. 179.

[38] Thus I would argue that material evidence should be one of the major sources for understanding artisanal knowledge.

[39] Francesca G. Bewer, 'The sculpture of Adriaen de Vries: a technical study,' Debra Pincus, ed., *Small bronzes in the Renaissance* (Washington, D. C.: Centre for Advanced Study in the Visual Arts, 2001), pp. 159-193.

Goldsmiths were involved in a tremendous number of innovative practices and a wide variety of activities on a daily basis. This comes through in any number of documents. For example, goldsmiths experimented with the metal casting that resulted in moveable type, they were engaged in gun and cannon casting and experimented with gunpowder. They established putting-out businesses that made jewellery and were active in testing dyeing techniques, lock and clock-making, money-lending and banking. Their involvement in alloying and assaying meant they were trained in arithmetic, often to a quite sophisticated level. Goldsmiths developed the technique of copper engraving, were involved in the beginnings of printing and began to call themselves architects, stressing their ability to design and oversee projects.[40] They were aware of their reputation and persona in a way that other craftspeople perhaps were not, or, at the very least, goldsmiths have left traces of such self-consciousness in a way that other trades have not. Although the objects that goldsmiths produced often functioned as temporary repositories of precious metals and thus frequently disappeared into the coinage of the realm,[41] historians still possess much material – both in the form of texts and objects – with which to study goldsmiths, and the goldsmith's workshop offers the historian much information on the generation of knowledge through practice that is characteristic of the crafts.

The workshop of Wenzel Jamnitzer (1508-1585), master goldsmith of Nuremberg, provides a good illustration of the diversity of activities in which goldsmiths engaged. It saw the production of a variety of objects, designs and written treatises, as well as documents of daily artisanal life in a city renowned for its artisans and trade.[42] Jamnitzer created elaborate sculpture that incorporated many different elements of goldsmithing techniques, including life-casts of reptiles, insects and small animals. In 1568, he published a book containing demonstrations of his practice and an exposition of the body of knowledge that underlay it. He also produced instruments of metallurgical and astronomical

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[40] For goldsmiths' involvement with casting, piece moulds and moveable type, see Wolfgang von Stromer, 'Zur 'ars artificialiter scribendi' und weiteren 'künsten' der Waldfoghel aus Prag und Girard Ferroses aus Trier, Nürnberg 1433-34 und Avignon 1444-46', '*Technikgeschichte*, 49 (1982): 279-289. For goldsmith jewellers, see for example, Bruce P. Lenman, 'Jacobean goldsmith-jewellers as credit-creators: the cases of James Mossman, James Cockie and George Heriot,' *The Scottish historical review*, 74 (1995): 159-177. For putting out enterprises, Oscar Gelderblom, 'The governance of early modern trade: the case of Hans Thijs, 1556-1611,' *Enterprise & society* (2003): 606-39, p. 618. For mathematics, J. Williams, 'Mathematics and the alloying of coinage 1202-1700,' *Annals of science* 52 (1995): 213-234.

[41] Goldsmiths were well aware that their work would most likely be destroyed and melted down within a generation. J. F. Hayward, *Virtuoso goldsmiths*, p. 32.

[42] *Wenzel Jamnitzer und die Nürnberger Goldschmiedekunst 1500-1700*, Catalog of the Germanisches Nationalmuseum, Nuremberg (Munich: Klinkhardt & Bierman, 1985).

calculation as well as surveying instruments, and he described and explained these instruments in an instructional text. Jamnitzer's workshop was embedded in the civic culture of Nuremberg in which practical mathematics was the common currency of merchants, instrument and map makers, astrologers and astronomers (including the mathematician and astronomer, Regiomontanus, who had settled in Nuremberg precisely because of this culture of mathematics). The products of Jamnitzer's workshop furthermore comprised part of a civic culture and culture of princely patronage that were highly performative and that prized inventiveness in and demonstration by means of wondrous objects. In this milieu, like Dürer before him, Jamnitzer gave clear voice to philosophical and epistemological ambitions.[43]

Jamnitzer's portrait, painted in 1562-63 by Nicholas Neufchatel, pictures him as goldsmith and esteemed citizen of Nuremberg surrounded by objects of his own making that embodied his designs, ideas, skills, and knowledge (Ill. 2 at the beginning of this essay). In his right hand, he grasps a pair of compasses, perhaps those he describes in his instrument book for scaling up a statue. In his other hand he holds another of his inventions, an instrument for comparing specific weights of metals in order to use them in sculpture. In a niche in the upper left corner stands a vase (similar to ewers made by Jamnitzer) full of delicate plants and flowers cast from life, a technique for which Jamnitzer attained particular fame. Two further examples of Jamnitzer's objects sit before him on the table, a statuette representing Neptune and the statuette's preparatory drawing. This too refers the viewer to Jamnitzer's methods for producing sculptures of the same weight in different metals, while indicating his ability to realise in metal a paper design.[44] The book before him may refer to his ambitions for publication that resulted after many years of work on the *Perspectiva corporum regularium* (1568). We see represented here the full range of Jamnitzer's artisanal production, both of objects and of knowledge.

A survey of Jamnitzer's activities, as they can be reconstructed from archival documents, gives a sense of this goldsmith's active and busy life. Born in Vienna, Jamnitzer learned goldsmithing there under his father. He moved to Nuremberg and became both a member of the Nuremberg goldsmiths' association and citizen of Nuremberg in 1534. During his life, Jamnitzer played a leading role among Nuremberg goldsmiths and assisted the city council with

[43] Pamela H. Smith, *The body of the artisan*, chs. 2-3.

[44] Jamnitzer's perception of himself as a designer, and his skill in drawing, is made clear in Klaus Pechstein, 'Zeichnungen von Wenzel Jamnitzer,' *Anzeiger des Germanischen Nationalmuseums* 1970: 81-95. Jamnitzer was probably instrumental in the requirements for the new 1572 Nuremberg Goldsmiths' Ordinance, which required the candidate to produce a work according to a drawn model (Pechstein, p. 89).

information and regulation of trade. In 1552, for example, Jamnitzer's advice about a mould for a coin was sought, and four years later, when the council interested itself in some sort of secret device, Jamnitzer helped question the possessor of this secret and was then asked to make four of the devices. He was called in to tell the council what an Augsburger had informed him about guns and weaponry.[45] Jamnitzer made objects on commission for the council as well as for many other nobles and burghers. He also made objects 'on spec', as when he sent his son to France with a table and a mirror on the occasion of the marriage (betrothal?) of the king's sister with the King of Navarra in 1572, hoping to sell them among the nobles gathered for the event. When his son suddenly died in Paris, the goods were confiscated. The Bürgermeister and the Council sent a letter on Jamnitzer's behalf seeking the return of his goods.[467]

Contracts for Jamnitzer's apprentices and journeymen attest to his busy workshop. He was asked to inspect the masterpiece of a journeyman goldsmith and to inform him why his work was considered deficient enough to prevent his attaining the rank of master.[47] His travels to Prague to deliver pieces commissioned by the emperor, including a writing casket, covered with small creatures cast from life, similar to that in Illustration 3, and a chamber fountain are also to be found in Council records because he had to get permission to leave the city whenever he travelled.[48] After Jamnitzer died, his heirs tried to sell a pumpworks he invented for extracting water from ditches to the city council. They also tried to collect the 1300 gulden owed him for a desk that was filled with mathematical instruments.[49]

Important insight into the working methods of a busy and sought-after goldsmith can be gained from a series of exchanges over commissions requested of Jamnitzer by the Archduke Ferdinand of Austria between 1556 and 1562. Jamnitzer was already busy with commissions from Emperor Maximilian II and so tried to excuse himself with the Archduke. When the Archduke persisted, Jamnitzer found a painter, Jacopo Strada, to prepare drawings and to discuss the project with Ferdinand. The work was to represent the creation of Adam and Eve in Paradise and was to include animals, plants, birds and mineral specimens already in the Archduke's possession. Strada wrote to the Archduke, offering himself as director of the work and specifying that a

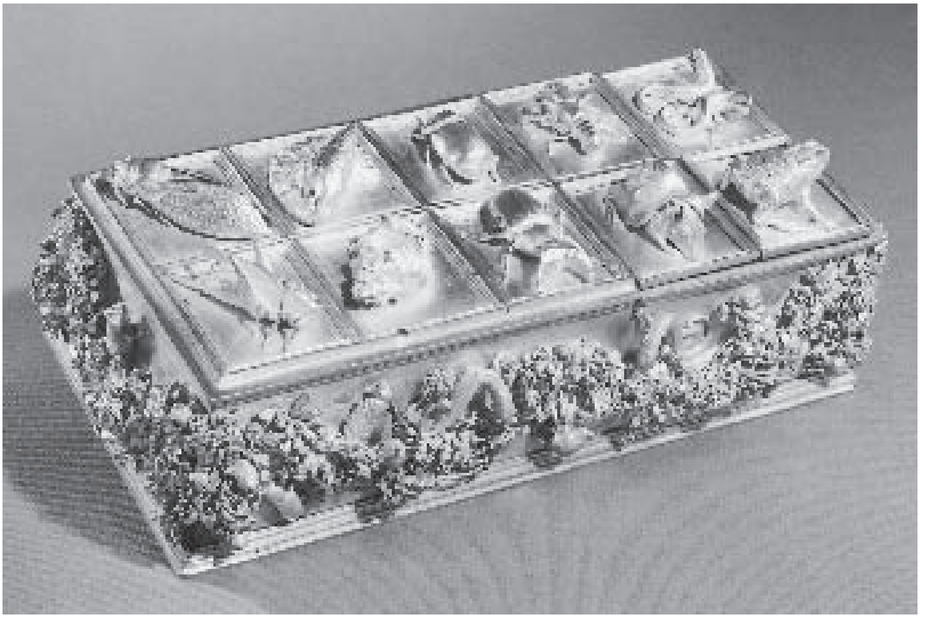
[45] Max Frankenburger, ed., *Beiträge zur Geschichte Wenzel Jamnitzers und seiner Familie. Studien zur deutschen Kunstgeschichte,* Heft 30 (Strassburg: Heitz, 1901; Fasc. Repr. Nendeln/Liechtenstein: Kraus Reprint, 1979), pp. 7-8 (coin mould); p. 13 (secret); p. 15 (guns and weaponry).

[46] Max Frankenburger, *Beiträge*, pp. 17-18.

[47] Ibid., p. 27. The journeyman could attempt the masterpiece again in six months.

[48] Ibid., pp. 20 (writing casket), 21 (chamber fountain).

[49] Ibid., pp. 35-36.



Ill. 3. Wenzel Jamnitzer, *Pen Case*, 1560-70, cast silver, 6 × 22.7 × 10.2 cm., Kunsthistorisches Museum, Vienna.

drawing of this room-sized creation would not be sufficient. Rather, a model would have to be made, as was usual when building palaces. Jamnitzer sent some of his cast animals from life to see if they were to the Archduke's taste, and Strada set off for Prague. After a year in which no work on the project took place, Jamnitzer tried to interest the Archduke in an already completed fountain, but Ferdinand insisted on his plan. The following year, Jamnitzer himself travelled to Prague on other business and discussed the fountain further with the Archduke. He promised to find a sculptor (Bildschnitzer) to carve the large animals (the smaller ones would be cast from life), and maintained that he was busy on the base and mechanism of the fountain, but could not say how long the whole work would take. The sculptor was finally found but he refused to work in Prague, preferring to stay home in Nuremberg and make the animals there. Jamnitzer sent Ferdinand a model of the base of the fountain, made, he said, with his own hands, along with a measuring stick so that the Archduke could measure all parts (and presumably envision the process of scaling it up). Ferdinand agreed to the sculptor working in Nuremberg, but insisted that he and the goldsmith must come to Prague where he would meet with them personally in order to give his orders about the size and appearance of the animals on the fountain and to discuss Jamnitzer's model for the base of the fountain. Jamnitzer waited months to receive silver and the scaled up measurements for the base from the Archduke. For two years, Jamnitzer worked desultorily on the fountain and after three tries got the water to spring high enough. He also informed the Archduke that because he had received no silver, he had manufactured some pieces with his own silver, but since he had not heard from the Archduke in a year, he melted them down again. Although this commission was nowhere near completion, Ferdinand charged Jamnitzer with a new one, sculptures of the four Evangelists. In his reply to the Archduke, Jamnitzer stated that 'as concerns the four Evangelists, I have spoken to the sculptor who will carve (*bosyrt*) them and with the one who will cast them in bronze (*messing*), and the one who chisels and gilds, and I have calculated what each wants for the work. So one couldn't make these Evangelists for under 30 gulden, nor in less than 3 months'.[50] Probably all these artisans were part of Jamnitzer's own workshop. This episode illustrates the negotiated nature of patronage, as well as the way in which Jamnitzer worked as much as an organiser of production as a hands-on artisan.

Making objects and knowing nature in the workshop

The objects that survive from Jamnitzer's busy workshop almost all make reference to the relationship of nature and art, and, more particularly, to the relationship of the artifice of nature and that of art. Along with his texts, they further manifest the active knowledge embodied in human craft, which can itself comprise a studied reflection of nature at work. Jamnitzer's *Perspectiva corporum regularium* (1568) and a manuscript set of instructions for his instrument collection, exemplify both the productive knowledge and the production of knowledge characteristic of the goldsmith's workshop.

The *Perspectiva* was part model book, part description of practice, part theoretical text and part virtuoso artisanal self-presentation and display. It is interesting to note that Benvenuto Cellini's autobiography and his treatises on metalworking function in identical ways to Jamnitzer's *Perspectiva*.[51] As I have explained elsewhere, in this book on representing polygonal solids, Jamnitzer gave his practices a mathematical and theoretical frame.[52] Engraved by Hans Sachs, this work depicted the five regular, or Platonic solids and their manifold variations. Following Euclid and Plato, Jamnitzer believed the five solids made

[50] The forgoing account is drawn from David v. Schönherr, 'Wenzel Jamnitzers Arbeiten für Erzherzog Ferdinand,' Th. Ritter v. Sickel, H. Ritter v. Zeissberg and E. Mühlbacher, eds., *Mitteilungen des Instituts für Oesterreichische Geschichtsforschung*, vol. 9 (Innsbruck: Verlag der Wagner'schen Universitäts-Buchhandlung, 1888), pp, 289-305 (Fascs. repr. Amsterdam: Swets & Zeitlinger, 1971).

[51] See Michael Cole, *Cellini and the principles of sculpture* (Cambridge: Cambridge University Press, 2002).

[52] Pamela H. Smith, *The body of the artisan*, pp. 79-80.

up the elements of nature. Fire was a tetrahedron, air an octahedron, earth a hexahedron, water an icosohedron, and the fifth element, heaven, a dodecahedron. All things, including all living creatures, were composed of combinations of these five solids, as Jamnitzer maintained could be seen in the 140 different solids he drew 'with his own heavy hand'. Knowledge of the five solids was also the foundation to any understanding of cosmology.[53]

The ambition displayed in Jamnitzer's *Perspectiva* to represent the cosmos also found expression in his elaborate cosmic fountain, begun in 1556 for Emperor Maximilian II, but only delivered twenty-two years later to Rudolf II in 1578. Ten feet high and five feet across, the fountain was assembled within a room (a *Zimmerbrunnen*, or chamber fountain), and it consisted of an attempt to replicate the entire divine, human and political cosmos.[54] It contained, according to a description probably written by Jamnitzer, 'not only physics and metaphysics, but also politics, as well as many wonderful philosophical and poetical secrets displayed and proven to the eyes'.[55]

The entire fountain sat on four figures – the four seasons, Flora (spring), Ceres (summer), Bacchus (fall) who holds wine grapes, Vulcan (winter) which show, according to the description, the inalterable band of nature that forms a framework for all of human life. These statues are the only part of the fountain not melted down in the eighteenth century, a fate shared by almost all table fountains and the vast majority of objects made from precious metals. Above these figures, the fountain was tiered, in accord with the structure of nature based on the four elements.

The lowest tier symbolised earth and was represented by Cybeles, goddess of the earth, a daughter of Saturn. She was surrounded by a grotto/mine with

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[53] Martin Kemp, *The science of art* (New Haven and London: 1990), pp. 63-64 points out the significance of the five Platonic solids.

[54] This marvel was melted down in the eighteenth century; only the Four Seasons that formed the base of this fountain still survive and are in the Kunsthistorisches Museum. See J.F. Hayward, 'The Mannerist goldsmith: Wenzel Jamnitzer,' *The Connoisseur* 164 (1976): 148-154 and *Wenzel Jamnitzer und die Nürnberger Goldschmiedekunst 1500-1700*. In the inventory of the *Kunstkammer* of Rudolf II, 1607-1611, the fountain is described as being contained in eighteen boxes marked with a particular seal. The contents of box no. 8 included a small book in which the entire meaning of the fountain was neatly written out on parchment. In box no. 9, there were two empty drawers in which the waterwheel was to be laid if the boxes were moved 'overland'. This box also handily contained a screwdriver with which the waterwheel could be dismantled. These documents are reprinted in Klaus Pechstein, 'Der goldschmied Wenzel Jamnitzer,' *Wenzel Jamnitzer und die Nürnberger Goldschmiedekunst 1500-1700*, pp. 67-70.

[55] Hans Boesch, ed., 'Urkunden und Auszüge aus dem Archiv und der Bibliothek des Germanischen Museums in Nürnberg,' *Jahrbuch der kunsthistorischen Sammlungen der allerhoechsten Kaiserhauses* 7 (1888): LXXXVII-XC. (Miscellaneahandschrift Nr. 28722 in octavo, which contains sketches 'die auf Reisen in den Jahren 1640-42 gemacht wurden'.), p. LXXXVII. The following description is from pp. LXXXVII-LXXXVIII.

all kinds of ores, silver and gold, with small animals, and silver flowers, cast from life, looking as if they were growing naturally out of the rock along lively little brooks, similar to the kind of object, collected by the Habsburgs, called Handsteine. Along the brook on Jamnitzer's fountain, a polishing mill, stamp mill, saw mill and hammer mill, were all driven by the water.

The next tier, a basin, represented Water, symbolised by Neptune standing on a shell drawn by hippopotamuses around the basin, battling strange sea monsters that first moved toward him threateningly and then fled from him. The constant movement and the to-and-fro of the battle signify both the ebb and flow of the sea around the earth and the fact that great lords and potentates must battle constantly with enemies of the common good.

Mercury represented the third tier, Air, and he swung and swooped off the fountain as if actually in flight. Under him a dark cloud spewed raindrops, and images of the four winds portended a furious storm. Flying into the storm were all sorts of birds, symbolic again of air, and four angels, carrying laurel wreaths, signifying the serving spirits that intervene between god and humans.

Above the tier of air, was that of fire, symbolised by Jove. Having reached this height, the fountain took on a complex admonitory political program which comprised a mirror for the prince, devoted to showing the order ('*polizei*') preserved by the emperor and the hierarchy of nobles as the representatives of god on earth.

Jamnitzer's fountain is part political statement about the wealth and might of the House of Habsburg, part mirror for the prince (manuals of decorum for princes that had been written since the middle ages) about his place in a cosmic hierarchy, part elegant mannerist ornamentation, part cosmological description (which portrayed nature as an all-encompassing structure for human activity, made up of four elements in constant ebb and flow) and part demonstration of Jamnitzer's combined mental and manual dexterity. The attentive prince took away from this marvellous fountain not only political and metaphysical lessons, but also a sense of the mechanics of water flow and the workings of a complex mechanical device.[56] Through such objects, artisans helped shape the taste of nobles and educated them about the workings of nature.

Jamnitzer's mathematical and discursive representation of the cosmos embodied in his book and his fountain was matched by his aim to survey the cosmos in a collection of instruments he invented. Towards the end of his life,

[56] Although the book of instructions for the fountain does not survive in an original copy, Jamnitzer's instrument manual, as well as the manuals that accompanied other mechanical collections, explained the mechanical workings of the devices. Oscar Doering, 'Des Augburger'.

Jamnitzer assembled a 'desk' containing a large variety of instruments in twelve drawers, all apparently manufactured by him, for a princely patron (probably the Duke of Saxony). Jamnitzer also wrote a text, meant to be sent along with the desk, that explained drawer by drawer how to assemble each instrument, its function and its use. Many of the instruments were accompanied by meticulous watercolour images that help to explain their function. This text, akin to an instruction manual, gives insight into the working practices and instruments of goldsmiths. It was organised around explaining the function of single objects to a person with no expertise whatsoever. It deals with instruments that Jamnitzer invented for his own craft for weighing, measuring, scaling up and down in making a sculpture, using different metals to create a sculpture of the same weight, creating cannon balls to fit into specific sized cannons and many other processes involving metals. In addition, the text includes surveying instruments of all kinds, for land, for mines and for sea, as well as time-keeping instruments that not only allowed one to figure the time, but also the rising and setting of the sun, the waxing and waning of the moon and the position of the sun in the zodiac. The text contains descriptions and instructions for compasses, calculations for finding longitude and latitude, for measuring the angle of planets and stars, for laying out and building from architectural plans and specially designed instruments for drawing ornamental designs. In addition, the desk contained a diverse collection of cut and carved stones, lenses and ornamental objects. This manuscript and the contents of the desk indicate the diverse nature of the activities in the workshop of a goldsmith. In addition, it illustrates the overlap between the concerns of scholars and artisans in studying nature, for example the use of instruments, and the necessity of both artisan and scholar to present a tangible object to a prince.[57] Throughout this text, Jamnitzer indicates that he is reading the works of scholars on cosmographic instruments and measurements, directing the reader to Peter Apian's *Cosmographia* at one point,[58] and making a distinction between his own ability to calculate the positions of the heavenly bodies and a 'learned man's' use of

57 This comes across particularly well in Jamnitzer's explanation of how to reckon the weight of a gold chain for a noble gathering. The full title of Jamnitzer's description of the Schreibtisch reads 'Grundlicher und Aigentlicher Underricht und Beschreibung der Künstlichen und nutzlichen Silbern und vergultenn Instrument die in dem Kunstlichen und wolgetzierten Schreibtisch in 12 Schubladen zufinden. Dessenn gebrauch dan fast dienstlich und bequem den freÿen Kunsten Geometrica und Astronomia. Neben andern viel verborgen und lustigen furgaben von Gewicht Und MaS und anders die alle dardurch erlernnet und auffgelöst mögen werden,' 2 vols., MSL 1893/1600 and MSL 1893/1601, National Art Library, Victoria and Albert Museum, vol. 1, f. 59r: 'Erklerung des Eichmasleins,' in which Jamnitzer describes a vessel by which one can calculate precisely the value of gold chain while at table with noble guests.

58 Wenzel Jamnitzer, 'Grundlicher und Aigentlicher Underricht und Beschreibung,' vol. 2, f. 70r.

these positions.[59] At another point, he points the reader to a more 'experienced individual' in sailing rather than explain certain aspects of a compass himself.[60] This manuscript attests to the shared and collaborative enterprise of knowledge making.

Jamnitzer was especially known and admired for his 'casting from life'. (Ill. 4) I have discussed the significance of casting from life as a way of knowing nature elsewhere, but it is important to realise that this style offered artisans the opportunity to display their art – their ability to imitate nature – both because the finished product was a perfect imitation of nature and because they imitated nature in the processes of smelting and casting. This imitation of nature comprised a form of natural knowledge, both in the techniques used to produce it as well as in the epistemological claims made by the artisans.[61]

An anonymous goldsmith's manual written probably in Paris in the late sixteenth century makes the investigative nature of casting from life particularly clear.[62] This manuscript appears to be a record of practice and contains a fascinating array of information and asides on all kinds of subjects, from pigment production, to drawing and painting, to making mortars, to casting from life, to planting trees, to early form of taxidermy for manufacturing curiosities in the form of composite animals (kittens and bats), to attracting pigeons, making papier mache masks, concocting medicines, tips for using clysters on people suffering with haemorrhoids and any number of other activities. But by far the bulk of the manuscript is given over to metalworking techniques. It is one of the only sources that provides insight into the process of casting from life, a technique developed in the fifteenth century in Padua in imitation of ancient practices.

Casting from life had only a short lifespan in Italy, but was reinvented in Nuremberg, where Jamnitzer was its most active and well-known practitioner. The Paris manuscript contains detailed instructions for preparing the materials, such as the sand and plaster, then catching the animals alive, keeping them, killing them, affixing them to the base of the mould, constructing the mould and the investment material, stripping the animal out of the box mould or burning out the creature, then casting the sculpture, and stripping it from the mould, either preserving the mould for further casting or destroying it. Generally, animals were killed by immersion in vinegar and urine so that they were not deformed by blows. Posing them in a lifelike manner was done by attaching them with pins and threads to a clay base. A thin plaster and sand solution was painted over them, and the whole thing was then fired in a kiln, which

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59 Ibid., vol. 2, f. 37v.

60 Ibid., vol. 2, f. 40v.

61 Pamela H. Smith, *The body of the artisan*.

62 Bibliothèque Nationale, Paris, Ms. Fr 640, R 62 039.

Ill. 4. Wenzel Jamnitzer, *Lifecast of a Lizard*, sixteenth century, lead, Staatliche Museen zu Berlin – Preußischer Kulturbesitz (Kunstgewerbemuseum). Photo: Jörg P. Anders.

hardened the plaster and burned out the organic matter. This formed a mould that was first cleaned out with mercury or by blowing and then poured with metal. Dead animals might also be pressed into a sand mould, out of which they could be lifted before the molten metal was poured in.

The goldsmith's manuscript gives unparalleled insight into the process of casting from life. More than this, it gives an unprecedented sense of the investigation of nature undertaken by this working artisan.

Catching lizards and snakes

Take a stick, pin a net with a slipknot to the top. Whistle and move the net nearer to the head of the lizard, and pull when it put its head inside the net. It is more difficult to take a lizard with your hands than a snake, because lizards bite without letting go, with a bite as strong as pincers.

You can take snakes with your hand, but cover your hand with a woollen cloth because the teeth of the snake can go through common cloth. You can recognise dangerous snakes by their blue eyes. They do not bite into water, as is known by crayfish catchers.[63]

Snakes

When they are caught they do not bite and if the snakes are not very large they cannot harm you. Before catching your snake, put your foot on it very close to the head, that way your snake cannot move its head at all and cannot bite you. A snake never moves in a straight manner, on the contrary, it moves in a crooked way. The man who taught me how to mould snakes didn't mind crooked attack from snakes. This man was accustomed to squeeze the snake 5 or 6 fingers from the end of the tail; that way the snake vomits the venom it has in his stomach, and hasn't the force any longer to bite. If by chance the snake bites you, cover your wound with fresh damp earth, which will kill the poison. You can do the same against toad venom.

Mould your snake before it becomes thin, and kill it a quarter-hour before moulding it.

Once snakes have eaten, they vomit food if you bother and shake them. They would also vomit if you press them with your foot; if you wound your snake with this pressure, it will not eat gladly anymore.[64]

Killing snakes in order to mould them

Some people put a drop of aqua fortis into the mouth of snakes in order to stupefy the animals. That way the head and the body look dead, but the head is still lively, and when you stick a needle into the head in order to fix it on your mould, the head moves and spoils and ruins everything. To kill your snake, put it into a bottle filled with good vinegar and a bit of brandy. Do the same with lizards and other similar animals.[65]

The goldsmith makes explicit natural historical observations and experiments on the behaviour of reptiles, as he instructs the reader in catching, keeping, feeding, killing and finally moulding the creatures. This comes through most clearly in the following passage:

63 Ms. Fr 640, R 62 039, folio 109r.
64 Ms. Fr 640, R 62 039, folio 108r.
65 Ms. Fr 640, R 62 039, folio 107v.

Moulding snakes

Before moulding your snake…do not remove its teeth, for [then]…snakes suffer gum pain and cannot eat. Keep your snake in a barrel full of bran, or, better, in a barrel full of earth in a cool place, or in a glass bottle. Give your snake some live frogs or other live animals, because snakes do not eat them dead. Also I've noticed that when snakes want to eat something or to bite, they do not strike straight on, on the contrary they attack sideways as do Satan and his henchmen. Snakes have small heads, but very large bodies; they can abstain from eating for 7 or 8 days, but they can swallow 3 or 4 frogs, one after the other. Snakes do not digest food all at once, but rather little by little. …If you worry and shake your snake, it will bring up digested and fresh food at the same time. Sometimes 2 or 3 hours after swallowing a frog, it can vomit it alive.

If your snake is long, mould it hollow, and if you want to mould it with its mouth open, put some cotton with a little melted wax into its mouth.[66]

Alongside such explicit natural historical observations are numerous experiments on the behaviour of sands, clays and firing techniques, as well as directives for the best methods of casting reptiles. For example, in discussing various kinds of sands to be used in box moulds, the goldsmith comments, 'The powder of the millstone of the maker of edge tools is very good to cast with copper, but do not use the powder from the cutler'.[67] At another point, he explicitly refers to the experimental nature of his work: 'Since my last experiences, I moulded with burned bone, clinker and burned felt'.[68]

We can see, then, how this goldsmith sought out the behaviour of animals and natural materials in a systematic and empirical way. The techniques by which casting from life was achieved involved significant investigation into the behaviour of animals and materials, an investigation akin to natural history. This is echoed in other artisans' manuals, which advise constant trial. 'It is necessary to find the true method by doing it again and again….;'[69] 'to have a superabundance of tests…not only by using ordinary things but also by varying the quantities, adding now half the quantity of the ore and now an equal portion, now twice and now three times…'.[70]

To conclude, a goldsmith's workshop was the site of an enormous variety of activities that were simultaneously productive and investigative. In many ways, the distinction between the investigation of nature and artisanal practice is a specious one for this period. Casting from life involved observation of nature of a type that might have been undertaken by a physician at the same

[66] Ms. Fr 640, R 62 039, folio 107r-v.
[67] Ms. Fr 640, R 62 039, folio 69v.
[68] Ms. Fr 640, R 62 039, folio 85v.
[69] Vannoccio Biringuccio, *The pirotechnia*, p. xvi.
[70] Ibid., pp. 143-144.

time. The naturalist-physicians Konrad Gesner and Leonhard Fuchs, for example, certainly did so in the same period.[71] Casting from life also required a knowledge of natural materials that at this time was more the province of the artisan than of the scholar, but which some scholars shared. Moreover, the instruments invented, manufactured and assembled as a collection by the goldsmith Wenzel Jamnitzer were just as much a part of an astronomer's world, such as Peter Apian, or even of the world of a merchant, such as the Augsburg merchant, Philipp Hainhofer. At the same time, these instruments and the other objects produced in Jamnitzer's workshop were inseparable from the pleasure and princely entertainment that comprised an integral part of the entire enterprise of knowing nature in early modern Europe. Both making objects and knowing nature were embedded in this larger social framework. It makes sense, then, as this collection of essays endeavours to do, to begin to form a vocabulary that better expresses the collaborative and mixed character of natural inquiry in the early modern period. Only through understanding the contingency of the production of natural knowledge and the ways in which making knowledge and objects is dynamic and emergent can we begin to incorporate a history of experiential knowledge into the narrative of what has been called the Scientific Revolution.

Primary sources

Anonymous, goldsmith's manuscript, Bibliothèque Nationale, Paris, Ms. Fr640, R 62 039.

Biringuccio, Vannoccio, *The pirotechnia*, trans. by Cyril Stanley Smith and Martha Teach Gnudi (New York: Basic Books, 1943).

Cellini, Benvenuto, *The two treatises on goldsmithing and sculpture,* trans. by C. R. Ashbee (New York: Dover, 1967).

Cennini, Cennino, *Il libro dell' arte (The craftsman's handbook)*, trans. by Daniel V. Thompson, Jr. (New York: Dover, 1960).

Jamnitzer, Wenzel, "Grundlicher und Aigentlicher Underricht und Beschreibung der Künstlichen und nutzlichen Silbern und vergultenn Instrument die in dem Kunstlichen und wolgetzierten Schreibtisch in 12 Schubladen zufinden. Dessenn gebrauch dan fast dienstlich und bequem den freÿen Kunsten Geometrica und Astronomia. Neben andern viel verborgen und lusitigen furgaben von Gewicht Und Maß und anders die alle dardurch erlernnet und auffgelöst mögen werden," 2 vols., MSL 1893/1600 and MSL 1893/1601, National Art Library, Victoria and Albert Museum.

Theophilus, *On divers arts*, trans. and introduced by John G. Hawthorne and Cyril Stanley Smith (New York: Dover Publications, 1979).

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[71] See for example, F. David Hoeniger, 'How plants and animals were studied in the mid-sixteenth century,' pp. 130-148, and James S. Ackerman, 'The involvement of artists in Renaissance science,' pp. 94-129, both in John W. Shirley and F. David Hoeniger, eds., *Science and the arts in the Renaissance* (Washington DC: Folger Books, 1985). See also Sachiko Kusukawa, 'From counterfeit to canon: picturing the human body, especially by Andreas Vesalius,' Preprint 281 (Berlin: Max-Planck-Institut für Wissenschaftsgeschichte, 2004).

In 1724, Johann Gabriel Doppelmayer, in his *Atlas Coelestis*, presented two maps of the Moon. The maps differ in selenographic details, graphic representation and nomenclature. The fact that Doppelmayer presented both maps face to face meant that topographic understanding of the Moon was not established.

ILLUSTRATION 5

Constructive thinking: a case for dioptrics

Fokko Jan Dijksterhuis

My son just made me laugh about the superscription of the letter of Mr. De Louvois, where it has 'to Mr. Huygens etc., mathematician'. He seems to take him for one of the engineers of his fortifications. I did not know I had craftsmen among my children.[1]

Thus wrote Constantijn Huygens in 1683 to the intermediary of the letter that François-Michel le Tellier (1639-1691), marquis of Louvois and superintendent of constructions to Louis XIV, had sent to his son Christiaan. Through the jeering we can sense the offence Constantijn took when his son was taken for an engineer. Huygens Sr. belonged, after all, to the top of the Dutch elite after a lifetime of service to the House of Orange, and the mathematical sciences had brought 'young' Christiaan to the court of Louis XIV. Not a family of craftsmen, indeed.

Yet, why would the mere word 'mathematician' excite such offence? Was Christiaan Huygens not Europe's most renowned mathematician at that time? Certainly he was, but he was no mere 'mathématicien'. That word denoted what modern historiography has come to call 'mathematical practitioners', the men who employed mathematics for utilitarian goals like water management, navigation, fortification and so on – artificers indeed, and far beneath the standing of the Huygenses. 'Géomètre' would be more apt to address Christiaan Huygens, indicating his social status and denoting the more academic status of his amateur scholarship. The words 'mathématicien' and 'géomètre' connoted a clear social distinction between the thinker and the doer, between the disinterested and the professional pursuit of mathematics.[2] Such a distinction ought not to be transgressed lightly.

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[1] Christiaan Huygens, *Oeuvres complètes de Christiaan Huygens*. Publiées par la Société Hollandaise des Sciences, 22 vols. (Den Haag: Martinus Nijhoff, 1888-1950). Cited as: Huygens, *OC* followed by volume number and pages. Huygens, *OC8*, pp. 456-457. Constantijn Huygens to Henri de Beringhen, 14 October 1683: 'Mon fils vient de me faire rire de la superscription de la lettre de Mr. de Louvois, où il ij a, à Monsr. Huygens &c. mathematicien. Il semble le prendre pour un des ingenieurs de ses fortifications. Je ne croijois pas avoir des gens de mestier parmi mes enfans'.

[2] John W. Olmsted, 'Jean Picard's 'membership' in the Académie Royale des Sciences, 1666-1667: the problem and its implications,' in *Jean Picard et les débuts de l'astronomie de précision au XVII^e siècle*, ed. Guy Picolet (Paris: Éditions du Centre National de la Recherche Scientifique, 1987), pp. 85-116, on pp. 86-87.

Yet, we may ask again, how could a well-versed courtier like Le Tellier make such a mistake? Was it not clear from Huygens' activities that he was no mere 'mathématicien'? In fact, it was not. True, he was a founding member of the Académie Royale des Sciences and had published on sophisticated mathematical theory, but his 'géométrie' had many features of 'mathématique'. *Horologium Oscillatorium*, his major work published in 1673 in dedication to Louis XIV, treated of the theory of pendulum motion in all its mathematical sophistication, but was centred around an artefact, the pendulum clock. In general, Christiaan Huygens tended to focus his mathematical inquisitiveness on instruments, trying to sort out their uses and workings and the possible improvement thereof.[3] On the basis of his mathematical activities it may be understandable that Christiaan Huygens should be mistaken for a 'mathématicien'.

The confusion over the distinction between different brands of mathematicians goes further, however, than the particular features of Huygens' mathematics. I would argue that it emanates from features of seventeenth-century mathematics in general. It is very difficult to distinguish inquisitive from inventive activities in seventeenth-century mathematics because, in my view, contemplation and manipulation are almost completely interwoven. It is hard, therefore, to make a clear distinction between 'mathématiciens' and 'géomètres' on the basis of their activities alone. The distinction was social and cultural, and was determined by the purposes for which mathematics was pursued. The historian is thus in a similar position to the anthropologist who describes the engagement of two groups with a ball and two goals, but who cannot know whether or not they are engaged in playing a game.

This paper deals with dioptrics, one of Christiaan Huygens' main interests and a field where the interwovenness of manipulation and contemplation is well visible. I offer a short history of dioptrics through the contributions of three prominent players, Descartes, Huygens and Hartsoeker, who not only shared common geographical space but who are also historically related through the circles they moved in and their successive intellectual and biographical connections. Through their works I will be able to discuss seventeenth-century dioptrics as a site of inventive intellectual, practical and cultural intersections, where making distinctions between what might be thought to intersect – science and technology!? – are rather counterproductive for a historian.

The mathematical blend of contemplation and manipulation is already apparent with Johannes Kepler, who coined the term 'dioptrics' in his 1611 *Dioptrice*. As part of 'optics', the mathematical science of the study of light

[3] Fokko Jan Dijksterhuis, *Lenses and waves. Christiaan Huygens and the mathematical science of optics in the seventeenth century* (Dordrecht: Kluwer Academic Publishers, 2004), pp. 255-259.

and vision, and next to 'catoptrics', as Euclid had named the study of light in reflection, the newly invented telescope called for a study of light in refraction.[4] Structured in deductive fashion, built up from definitions and axioms, the heart of *Dioptrice* lies nevertheless in a range of 'problemata' that explain how to bring about a particular effect by means of properly arranged lenses, as for example the configuration of two convex lenses (the type of telescope first proposed by Kepler): 'Problem. By two convex lenses, present visibles larger and distinct, but in inverted position'.[5] Rather than *proving* that this configuration of lenses results in a magnified but inverted picture, Kepler explained *how to bring about* the effect, by means of mathematical argument using previous propositions and axioms. Towards the end of *Dioptrice*, propositions and problems are fused almost completely: 'Proposition. Problem. To find the point of convergence of a meniscus lens. Or, the thinner the lens, the further the convergence'.[6]

Dioptrics from Paris to Holland

In the summer of 1625 Descartes returned to Paris after years of travel through Europe. He found his acquaintances, incited by Mersenne's cataloguing of scientific issues, busily engaged with matters optical and quickly joined in.[7] Descartes was not new to these issues; a note from 1620 shows that he had already read Kepler creatively, interpreting the mathematical analysis of refraction in *Paralipomena* in physical terms.[8] During the next year or two, he would extend his inquiry into the physico-mathematics of refraction to the discovery of the sine law. This achievement and its rendering in Descartes' later writings have been extensively discussed in history of science literature, most searchingly and convincingly by Schuster, and I do not intend to rehearse

[4] Johannes Kepler, *Gesammelte Werke*, ed. Walther von Dyck and Max Caspar, 17 vols. to date (Munich: Beck, 1937-). Cited as: *KGW* followed by volume number and pages. Kepler, *Dioptrice*, dedicatory letter (*KGW IV*, 331). 'Ac cum Euclides Optices speciem fecerit Catoptricen, quae de radio repercusso agit; nomine deducto à praecipuo hujus generis machinamento, Speculis, eorem mira et jucunda varietate: ad exemplum hoc meo libello natum est nomen Dioptrice;…'

[5] Kepler, *Dioptrice*, 42 (*KGW IV*, 387). 'Problema. Duobus convexis majora et distincta praestare visibilia, sed everso situ'.

[6] Kepler, *Dioptrice*, 72 (*KGW IV*, 409). 'Propositio. Problema. Punctum concursus pro Menisco invenire. Seu, quantum attenuatur lens, tantum elongari concursum'.

[7] Marin Mersenne, *Quaestiones celeberrimae in Genesim* (Paris, 1623); Mersenne, Marin, *La vérité des sciences* (Paris, 1625), pp. 229-230.

[8] John A. Schuster, 'Descartes *opticien*. The construction of the law of refraction and the manufacture of its physical rationales, 1618-29,' *Descartes' natural philosophy*, ed. Stephen Gaukroger et.al. (London: Routledge, 2000), pp. 258-312, on pp. 279-285.

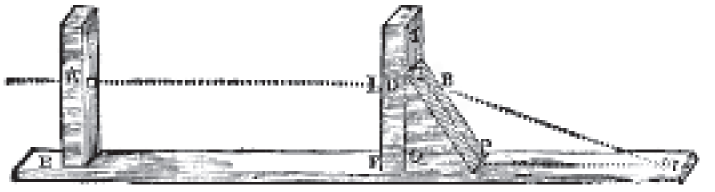
the story here.[9] I am interested in the context in which Descartes' optical studies took place, which was a context of intense collaboration on optical instrumentation. The Parisian scene Descartes encountered on his return was heavily engaged with mirrors and lenses, trying to devise *and* realise the shapes that would focus rays perfectly. When Descartes joined in, his activities were not just intellectual but equally immersed in material pursuits with which his physico-mathematical reflections were closely entwined. The discovery of the sine law cannot be singled out as the principal achievement of this episode – as literature generally presents it – for it was part of a project of producing a perfectly focussing lens, to which it was inherently connected.

The collaboration in which Descartes participated in the Paris of the mid-1620s nicely shows what it took to do dioptrics. The idea was to produce a perfect lens; that is, a lens that does not suffer from spherical aberration. An ordinary spherical lens, where the section of a face is part of a circle, does not refract incident parallel rays to a single point. Instead, the refracted rays intersect the axis of the lens over a small region. The image of a point of the object is therefore slightly blurred. The fact that spherical lenses do not have a perfect focus had been known for a long time; Della Porta had pointed it out and Kepler had extensively discussed the matter. The question now was what lens could bring rays to a perfect focus. To tackle the problem one needed means to determine the right shape of the lens, means to realise this shape materially and the means to render the shape into glass. The Parisian team that solved the problem had all these means: command over dioptrical theory, mathematical draughtsmanship, and lens grinding expertise. Around 1627, Descartes, the mathematician Claude Mydorge and the lens maker Jean Ferrier managed to produce a hyperbolic lens.

One tends to attribute the separate skills to the individual members: Descartes the theorist, Claude Mydorge the draughtsman, Jean Ferrier the artificer. Yet, the success was much more of a collaborative effort in which these skills combined through those individuals. For example, they made a device to measure angles of refraction, consisting of a glass prism fitted in a wooden visor, to direct the rays (Ill. 6).[10] As it turns out, this device offered a framework for thinking about the mathematical relationship between incident and refracted

[9] John A. Schuster, 'Descartes and the scientific revolution 1618-1634: an interpretation' (Unpublished PhD dissertation, Princeton University, 1977), summarized and updated in John Schuster, 'Descartes *opticien*.'

[10] It is described in Descartes, *La Dioptrique*, discours dixième AT VI, 211, (*Oeuvres de Descartes*, ed. Charles Adam and Paul Tannery, 2nd edn., 11 vols. (Paris: 1974-1986). Cited as *AT* followed by volume number and pages) and draws on Kepler's *Dioptrice* where a similar setup is discussed.



Ill. 6. Set-up used by the Paris trio to investigate the measure of refraction as presented in *La Dioptrique*, p. 137.

rays, much like Harriot's astrolabe immersed in water.[11] In addition, the oldest source of the exact refractive relationship discovered during the project is a letter from Mydorge, in which he explained how any refracted ray can be constructed by means of a cosecant rule when the refraction of a single ray is known.[12] This cosecant rule was the origin, as Schuster has convincingly argued, of the law of sines.[13] In other words, the 'law' of refraction was a rule of mathematical construction that in its turn was rooted in a device for measuring refraction.

In fact, the term 'law of refraction' is historically suspect, as it was rarely referred to as a 'law' in the seventeenth century. Even Descartes, who more or less established the conception of nature being governed by laws to be discovered by the natural inquirer, never talked about laws of nature with regard to refraction, or optics in general.[14] During the seventeenth century, the regular relationship between incident and refracted rays was conceived as the *measure* of refraction.[15] Rather than 'law of sines' one spoke of 'ratio of sines' which

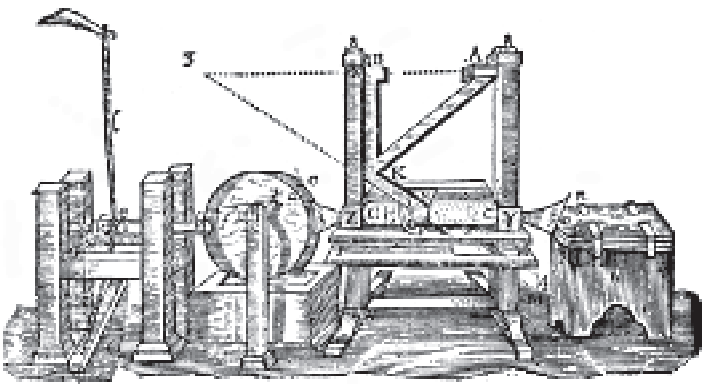
[11] William R. Shea, *The magic of numbers and motion. The scientific career of René Descartes* (Canton: Science History Publications, 1991), pp. 152-155. For Harriot see Johannes Lohne, 'Zur Geschichte des Brechungsgesetzes,' *Sudhoffs Archiv* 47 (1963): 152-172, on pp. 159-160 and Johannes Lohne, 'Kepler und Harriot. Ihre Wege zum Brechungsgesetz,' in *Internationales Kepler-Symposium, Weil der Stadt (8. Bis 11. August 1971): Referate und Diskussionen*, ed. Fritz Kraft et.al. (Hildesheim: Gerstenberg, 1973), pp. 187-213, on pp. 202-203.

[12] Marin Mersenne, *La correspondance du P. Marin Mersenne*, ed. P. Tannery and C. de Waard (Paris: Editions du CNRS, 1933), in volume 1, pp. 404-415.

[13] John Schuster, 'Descartes *opticien*,' pp. 272-277.

[14] For Descartes' concept of laws of nature see Rienk Vermij, 'Een nieuw concept: de wetten der natuur,' in *Kometen, monsters en muilezels. Het veranderende natuurbeeld en de natuurwetenschap in de zeventiende eeuw*, ed. Florike Egmond et.al., (Haarlem: Uitgeverij Arcadia, 1999), pp. 105-119.

[15] In contrast to the common practice in (the new) natural philosophy of the seventeenth-century, the term 'law' was rarely used in optics. With respect to refraction, Kepler used 'mensura' (*KGW* II, 78; Kepler, *Optics*, 93). Descartes spoke of the laws of motion but of 'mesurer les refractions' (*AT VI*, 102). In his optical lectures of 1670 Newton used 'regula' and 'mensura' (Newton, Isaac, *Optical papers of Isaac Newton*, ed. Alan.E. Shapiro, 1 vol to date, (Cambridge: Cambridge University Press, 1984-),



Ill. 7. The lens grinding machine devised by Descartes/Ferrier as depicted in the tenth discourse of *La Dioptrique*.

was a means of mathematical construction, to be performed in the mind or on paper as well as materially. In this way we see how the skills combined by Descartes, Mydorge and Ferrier were interwoven at the very heart of dioptrics: the measure of refraction. The project they were engaged in was to produce a perfectly focussing lens; to know how to measure refractions was one of its products – rather than the lens being the application of a theoretical insight, as it is often presented.[16] Eventually, in *La Dioptrique*, Descartes would describe a lens-grinding machine that embodied the fruits of the project and thereby incorporated the knowledge contributed by Ferrier, Mydorge and Descartes himself: it mechanised the generation of the desired curve and its transfer to glass (Ill. 7). The actual design of the machine came about after their collaboration, when Descartes was already in Holland, but through their correspondence Ferrier continued to give crucial input.[17]

volume I, pp. 168-171 & 310-311). In *Opticks* he used 'proportion' or 'ratio' of sines (Newton, *Opticks or a treatise of the reflections, refractions, inflections & colours of light. Based on the fourth edition London 1730* (New York: Dover Publications, extended edition 1979), pp. 5-6 & 79-82) as did Huygens in the 1653 manuscript of his *Dioptrica* (Huygens, *OC 13*, pp. 143-145.). In *Traité de la lumiere* he simply called the sine law the 'principale proprieté' of refraction (others are its reciprocity and total reflection) (Huygens, Chrisiaan, *Traité de la lumiere. Où sont expliquées les causes de ce qui luy arrive dans la reflexion, & dans la refraction. Et particulierement dans l'etrange refraction du cristal d'Islande, par C.H.D.Z., aved un discours de la cause de la pesanteur* (Leiden, 1690), pp. 32-33). In his notes he sometimes spoke of 'laws' or 'principles' (*OC 13*, p. 741) as he did in the *Dioptrica* prepared around 1666 (*OC 13*, pp. 2-9).

16 William Shea, *Magic*, pp. 157-159; Stephen Gaukroger, *Descartes. An intellectual biography* (Oxford: Clarendon Press, 1995), pp. 139-146 and 190-195.

17 William Shea, 'Descartes and the French artisan Jean Ferrier,' *Annali dell'Istituto e museo di storia della scienza di Firenze* 7 (1982): 145-160.

In late 1628 or early 1629, Descartes left Paris for the relative seclusion of Holland. He did not bring the expertise in dioptrics that had surrounded him in Paris. Despite initial plans to have Ferrier come over, in the end Descartes kept his distance and even broke off their correspondence. So he had to find skilled Dutchmen. During his earlier sojourn in Holland around 1619, Descartes had become acquainted with Isaac Beeckman, who had influenced his ideas on mathematics and natural philosophy decisively and who had been building a profound knowledge of, among others things, dioptrics.[18] Their relationship had cooled down, however, and Descartes first went to Franeker, where Adriaan Metius held the chair of mathematics. Metius taught and published extensively on mathematical instruments, and had written about the invention of the telescope by his brother, Jacob Metius of Alkmaar.[19] Metius had no expertise in the manufacture of optical instruments, though; earlier he had not even been able to employ his brother to acquire telescopes, and had gone to Middelburg to find suitable telescope makers. Descartes stayed a year in Franeker, before moving on to Amsterdam in 1630, the first of several residences he took all over the Dutch Republic during the next decade.[20] In 1635, Descartes established a close relationship with Constantijn Huygens, who would quickly become an important patron for his scholarly affairs.[21]

Huygens immediately promised to assist Descartes with all means necessary for his dioptrical work.[22] During Frederik Hendrik's campaign in the eastern Netherlands from May to December 1635, Huygens managed to have a hyperbola drawn and a lens made in accordance with it by an Amsterdam artisan, but Descartes was not satisfied with the result.[23] The next year they had a lens made with a hyperbola drawn by Descartes himself, but the resulting

[18] Beeckman kept a fascinating journal of his ideas, explorations, and so on that deserves to be studied in more detail: published as *Journal tenu par Isaac Beeckman* and available online at http://www.historyofscience.nl. On the exchange between Descartes and Beeckman see John Schuster, 'Descartes and the Scientific Revolution'; Stephen Gaukroger, *Descartes*, pp. 68-103.

[19] When Hans Lipperhey applied for a patent to the Dutch States General in 1609, Jacob Metius disclosed that he had also made such an instrument, one of the reasons the application was turned down.

[20] Deventer (1632), Amsterdam again (1633), Utrecht (1635), Leiden (1636), Egmond (1637) and Leiden (1640).

[21] They had already met one time in 1632, at home with Jacob Golius, professor of oriental languages at Leiden, who also had taken up the chair of mathematics in 1629.

[22] Willem Ploeg, *Constantijn Huygens en de natuurwetenschappen* (Rotterdam: Nijgh & van Ditmar n.v., 1934), pp. 33-34.

[23] Constantijn Huygens, *De briefwisseling van Constantijn Huygens (1608-1687)*, Uitgegeven door J.A. Worp, 6 vols. (Rijks geschiedkundige publicatiën. Grote serie; 15, 19, 21, 24, 28, 32) (Den Haag: Martinus Nijhoff, 1911-1917), letters 1269, 1270, 1322, 1329, 1369 and 1392.

surface turned out to be too irregular.[24] A final effort was made a year later, with Huygens in the field in the southern Netherlands. This time, Frans van Schooten the younger was employed to draw a suitable hyperbola. Van Schooten, the son of the professor of Dutch mathematics at the Leiden engineering school, studied mathematics and was busy climbing the patronage ranks in The Hague at that time. Still, the results did not satisfy: the lenses were inaccurate and not well polished.[25] After two years, the fruitless project was abandoned. Possibly the weak link had been the lens grinder, a 'master Paulus' from Arnhem, but it is certain that the fruitful combination of expertise necessary to do dioptrics was not established as it had been in Paris.[26]

The dioptrics project that Huygens had taken charge of did bear fruit, however, in the form of Descartes' *La Dioptrique*. Publishing on the subject was another way of doing dioptrics, and here too Descartes' employed the necessary skills. Huygens' network and resources provided a critical audience – Descartes had read to Huygens from his manuscript in 1635 – and enabled the production of the book itself.[27] *La Dioptrique* contained Descartes infamous physico-mathematical account of refraction, but also extensive discussions of vision and the physiology of the eye, and – perhaps most important – a means of perfecting vision by extending the capacities of the eye. Ribe has wonderfully argued how *La Dioptrique* expounds a daring vision of, not just remedying human shortcomings, but even improving on nature by artificial means.[28] In this Descartes drew not only on his collaboration with Ferrier and Mydorge, but also on his engagements with Dutch experts. In Amsterdam he had performed dissections and experiments on various kinds of eyes with the anatomist and doctor Vopiscus Plempius, which went into his account of the eye. The draughtsman's skills of Van Schooten went into the illustrations, but not only *as* illustrations. *La Dioptrique* introduces the conic sections required for perfectly focussing lenses in much the way gardeners outline a flower bed; the ellipse, for example, was made by guiding a stylus with a cord around two pegs (Ill. 8).[29] This was a practical means of realising the central idea of *La Dioptrique*: improve vision by using aspherical lenses.

Descartes had explained that *La Dioptrique* needed to be comprehensible to unschooled readers, and that he had therefore left out all mathematical intricacies. But the mathematics was there, of course. The method of drawing ellipses

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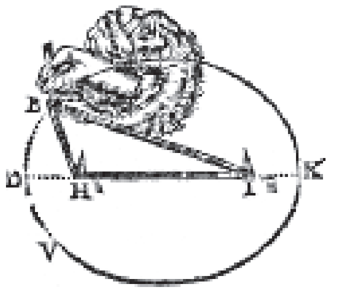
[24] Constantijn Huygens, *Briefwisseling*, letters 1392 and 1731.
[25] Constantijn Huygens, *Briefwisseling*, letters 1704 and 1993.
[26] Willem Ploeg, *Constantijn Huygens en de natuurwetenschappen*, pp. 36-37.
[27] Constantijn Huygens, *Briefwisseling*, letter 1277.
[28] Neil M. Ribe, 'Cartesian optics and the mastery of nature,' *Isis* 88 (1997): 42-61, on pp. 60-61.
[29] Alette Fleischer informs me that ellipses very rarely figured in gardens. She could find only one horticultural book discussing them.



Ill. 8. The 'horticultural' method of drawing an ellipse as illustrated by Van Schooten in the first edition of *La Dioptrique*, p. 90.

is based on the property of the ellipse that the sum of distances of a point to each focus is constant. By embodying this property of the ellipse, the peg-and-rope construction *was* the ellipse. Like the ratio of sines, the way to construct a refracted ray *was* the mathematics of refraction. The horticultural ellipse embodied the very heart of Cartesian dioptrics. It assembled the conceiving, drawing, cutting and grinding of a perfect lens. And in this way, it brought together the skills of all those involved in Descartes' dioptrics project: Descartes himself, Mydorge, Ferrier and Van Schooten. With the horticultural construction of ellipses, we get not only to the heart of *La Dioptrique*, but also to the heart of (seventeenth-century) mathematics. After all, to construct something – be it mentally, on paper or materially – is to do mathematics. This is clear in *La Géométrie*, where Descartes elaborated the mathematical intricacies he spared the skilful readers of *La Dioptrique*. The Cartesian ovals that underlie the dioptrical conic sections are equally constructions acquired by (mental) combinations of points, lines and curves. The roots of *La Géométrie* lie, after all, in Descartes' design of a compass to produce mean proportionals, which inspired in its turn his stranded project to develop a 'mathesis universalis'.[30] Manipulation and contemplation are here the same act.

Dioptrics from The Hague to Paris

'Now, however, I am completely into dioptrics'.[31] In late 1652, Christiaan Huygens wrote to Frans van Schooten, with whom he had studied mathematics

[30] William Shea, *Magic*, pp. 35-57; John Schuster, 'Descartes' mathesis universalis: 1619-1628,' in *Descartes: philosophy, mathematics and physics*, ed. Stephen Gaukroger (Sussex: The Harvester Press, 1980), pp. 41-96.

[31] Huygens, *OC1*, 215. 'Nunc autem in dioptricis totus sum…'

previously, about a discovery he had made. He had found out that the ovals Descartes had derived in *La Géométrie* in order to acquire the shapes of perfectly focussing lenses in some cases reduce to circles. In other words, in some configurations ordinary spherical lenses do not suffer from spherical aberration. Although Van Schooten was sceptical, he did include Huygens' proof in the second edition of *Geometria à Renato Des Cartes* (1659).[32] The proof itself is a fine example of the mathematical talents the 23-year-old Huygens had started to display. Now that he was 'complete in dioptrics', the question was what it *took* to do dioptrics.

It took, in the first place, proficiency in mathematical theory. Soon after his discovery, Huygens set out to elaborate a treatise on dioptrics, in which he used the 'ratio of sines' to analyse the imaging properties of spherical lenses and their configurations.[33] He did so with the utmost rigour, deriving for example the focal distances for any kind of lens, taking into consideration the thickness of the lens and regarding the focus as a limit point of the intersections of the refracted rays. Only when he had found exact proportionalities between the shape of the lens – thickness, curvatures of the faces – and its focal distance, did he show how these reduced to the simple – and already familiar – proportionalities for thin lenses. Surprisingly, Huygens was the first to apply the ratio of sines to spherical lenses. In *La Dioptrique*, Descartes had only discussed his perfectly-focussing, non-spherical lenses. Kepler had, of course, not known the exact measure of refraction and had therefore made do with approximations, but after *Dioptrice* spherical lenses had not been the subject of mathematical analysis. The fact that Huygens was the first in several decades to subject spherical lenses to mathematical analysis is telling about his ideas on mathematics. As Kepler had proclaimed, a mathematical instrument should only be used when it was understood exactly. This is precisely what Huygens' treatise offered: an exact explanation of the imaging properties of telescopes. Yet the fact that Huygens was the first in all these years to seek an exact understanding of the telescope is also telling in regard to the perceived relevance of thorough mathematics to dioptrics. Not until the telescope was turned, around 1670, into an instrument of precision instead of qualitative observation did telescopists turn to mathematical theory for exact elucidation of its effects.[34]

Huygens' elaboration of an exact theory of spherical lenses in 1653 was to a considerable extent prompted by his dissatisfaction with Descartes' handling of

[32] In a letter to Van Schooten, Huygens elaborated his discovery two years later: *OC1*, pp. 305-306.
[33] Huygens, *OC13*, pp. 1-271. Discussion of the history and content of this manuscript in Fokko Jan Dijksterhuis, *Lenses and waves*, pp. 12-24.
[34] Fokko Jan Dijksterhuis, *Lenses and waves*, pp. 41-51.

dioptrics. Rather than explaining the workings of actual telescopes, Descartes had indulged in the fancies of ideal, yet fictitious, lenses. Indeed, after the initial Paris success and despite sustained efforts by many, no one had succeeded in producing usable non-spherical lenses. Descartes, Huygens felt, had neglected the art of lens making and telescope use, which ought to be the foundation of dioptrics in every respect.

So, to do dioptrics, Huygens also needed knowledge of actual telescopes and their manufacture. A couple of days after he had written to Van Schooten, he sent a letter to Gerard van Gutschoven in Antwerp inquiring about the art of lens making. For example, what material is used to make grinding forms? What glue secures the glass to the grip? How do you check the spherical figure of the result?[35] Around the turn of the year, Huygens was contacting acquaintances who possessed high-quality telescopes; in his notes we find a description of a telescope made by the famous instrument maker Johann Wiesel of Augsburg. Huygens recorded the exact properties of the lenses and their configuration carefully.[36] Through his cousin Daniel de Vogelaer he acquired instructions by Wiesel himself for the use of a six-lens telescope.[37] It was not long before Huygens, together with his brother Constantijn, began grinding his own lenses and building telescopes. In 1655 he discovered a satellite of Saturn and shortly after employed his telescopes – as well as his imagination – to sort out the odd appearance of that planet.[38] Over the years Huygens made notes on his lens grinding experiences, which reveal the profound skill and patience necessary to master the art. Holding and moving the glass in the mould required a complete control over the hands that had to be maintained for hours. 'It is best to be alone…', Huygens remarked at one point.[39] Labouring at it could be a frustrating affair:

At first I ground the other side wrongly: the reason for this was that I either took too much water in the beginning, or I did not polish on the right spot. I first corrected it somewhat by polishing at the right spot again; then with more polishing it once again got worse'.[40]

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[35] Huygens, *OC1*, p. 192.
[36] Huygens, *OC13*, pp. 598-599.
[37] Huygens, *OC1*, 308-309.
[38] Albert van Helden, 'Huygens and the astronomers,' in *Studies on Christiaan Huygens. Invited papers from the symposium on the life and work of Christiaan Huygens, Amsterdam, 22-25 August 1979*, ed. Henk J.M. Bos et.al. (Lisse: Swets & Zeitlinger, 1980), pp. 147-165, on 150-154.
[39] Huygens, *OC17*, 294. ''t is best alleen te sijn'.
[40] Huygens, *OC17*, 294. 'De andere sijde sleep ick eerst eens mis: daer de oorsaeck van was, of dat ick in 't eerst te veel water nam of dat ick niet op de goeije plaets en polijsten. ick verbeterdense eerst wat met op de rechte plaets noch eens te polijsten; daer nae met noch meer polijsten wierd het weer erger'.

Eventually, Huygens acquired a 'good' four-and-a-half foot bi-convex lens.

During the next ten years or so, Huygens concentrated on making telescopes and astronomical observations. It was not until after he had developed an eye-piece consisting of three lenses, configured in a very advantageous way to produce optimal images, that he returned to theory. Again, he invoked mathematics to explain the realised effect of lenses, but this time he also started to tinker with lines and circles to find even better configurations. The realisation that the disturbing effect of aberrations could be lessened by a proper configuration of lenses made him look for a way to remove them altogether.[41] After elaborating an exact theory of spherical aberration, in the mid-1660s Huygens managed to derive the specifications of lenses that would mutually cancel out the aberration.[42] It proved hard to realise the required lenses – in Paris, where Huygens was living by then, he could not find satisfactory glass and sufficiently skilled lens makers, and instructing his brother in The Hague was time-consuming. In the end, the design was useless, for it did not remedy chromatic aberration, a disturbance Newton showed to be inherent to refraction in 1672. Huygens then abandoned his project of using ordinary spherical lenses to produce perfect images.

In light of Huygens' dioptrics, the confusion over his status as 'mathématicien'/ 'géomètre' seems understandable. At one and the same time, he used mathematics to improve telescopy and he pursued mathematics to develop dioptrics theory. The tinkering with glass and lenses in moulds and telescopes was just the other side of the tinkering with circles and lines on paper and in the mind. Huygens' mathematical analyses were clearly aimed at understanding and, were it possible, improving the instrument and its use, but on the face of it this added little to what was known from experience. Furthermore, in his mathematical rigor Huygens often went much further into mathematical analysis than was required for the issues of telescopy involved. Scholarship guided his studies no less than utility, and it is difficult to determine the ultimate purpose of his dioptrical pursuits.

The strikingly intertwined characters of manipulation and contemplation in Huygens' dioptrics (as well as his pursuits in other mathematical sciences) may perhaps be explained as mere personal idiosyncrasies, but I think that would only partly explain it. As we saw with Descartes, as well as, in passing, with Kepler, dioptrics theory was closely linked with the construction and deployment of telescopes. Mathematical analysis was just one, particular way of getting to grips with understanding and using the instrument, together with tactile actions like grinding lenses, building telescopes, erecting them, and so on;

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41 Fokko Jan Dijksterhuis, *Lenses and waves*, 63-67.

42 Fokko Jan Dijksterhuis, *Lenses and waves*, 73-83.

it was an activity that few telescopists during the first half of the seventeenth century saw as particularly relevant for their art. Yet, when it came to mathematical analysis, it is difficult to distinguish between manipulation and contemplation without considering some external attributed purpose. I think this has something to do with the nature of mathematical analysis, where contemplation consists of manipulation. The manipulation of numbers, symbols, figures, and so on is carried out even though what those things represent is not evident. Seventeenth-century mathematics was to a large extent 'mixed', in the sense that mathematical objects represented concrete objects in varying degrees of abstractness. Even 'mathematica pura' was understood to treat of real space and quantity, the rational purification by Cauchy and the like still being at least one-and-a-half centuries away.[43] It is not, therefore, clear *a priori*, when mathematicians/geometers tinkered with lines and circles, what it was that they thought they were manipulating, and circumstantial evidence is needed to determine whether the purpose of mathematical analysis was 'merely' to make something or to gain a deeper understanding of the world. Whether, in other words, one was dealing with a craftsman or a philosopher.

To write and publish was a very scholarly act in the seventeenth century, it seems. In this sense, Huygens' dioptrics never became scholarly, for he would never get around to publishing his theories of lenses and telescopes. He did not do so for a quite unscholarly reason: without a design for a perfect yet feasible instrument like the clock of *Horologium Oscillatorium*, the publication of a treatise on dioptrics seemed futile. Apparently he thought 'just' a theory of lenses and telescopes was not enough for publication. So, the primus of the Académie failed to enlighten his fellows in the republic of letters on the mathematical secrets of lenses and telescopes. Demand for a mathematical treatment of dioptrics did exist; Huygens had been urged to publish since he had hinted at his 'dioptrics' in *Systema Saturnium* (1659). People had to wait for the next generation of telescopists, who were turning the telescope into an instrument of precision by inserting micrometers and aligning it on measuring devices. Writing on dioptrical theory of the kind Huygens had elaborated – an exact analysis of spherical lenses by means of the ratio of sines – was subsequently done by the 'mathématiciens' of the Paris and Greenwich observatories: the earth measurer Jean Picard and the celestial cartographer John Flamsteed.

Employing the telescope as a measuring instrument was not undisputed. In 1672 Flamsteed spawned a debate with the Gdansk astronomer Hevelius when he published a letter discussing his methods of measuring astronomical

[43] Gerard Alberts, *Jaren van Berekening. Toepassingsgerichte initiatieven in de Nederlandse wiskunde-beoefening 1945-1960* (Amsterdam: Amsterdam University Press, 1998), pp. 61-87.

angles.[44] Hevelius thought the telescope was unreliable as an exact instrument, because of its imperfections and the difficulty of aligning it accurately. In response, Flamsteed and Picard turned to paper, to enquire into the mathematics of lenses and their configurations. Picard read his account at the Académie (parts of it were published posthumously after his early death), whilst Flamsteed read his at Gresham College (his lectures were the basis of William Molyneux's *Dioptrica Nova* of 1692).[45] They invoked mathematics to show that telescopic observations were reliable. It is noteworthy that Flamsteed and Picard turned to paper to explain and justify the use of the telescope as a measuring instrument, rather than, for example, having their observations speak for themselves. Whoever they may have convinced, Hevelius was not among them. He relied on his acute vision, of which the British had been quite sceptical. After a visit to Gdansk, Halley had to report back home that Hevelius indeed had excellent vision. The reliability of his observations needed to be established by foreign witnesses, just as Flamsteed and Picard used a mathematical account to vindicate their instrumentation.

From dioptrics to natural philosophy

The writings of Picard and, more explicitly, Flamsteed reveal an underlying goal of their accounts: to distinguish relevant mathematics from irrelevant digressions on the telescope, be it either mathematics too abstract or philosophy too lofty. Saying something to the point on telescopes required more than book knowledge. To do dioptrics required both skill and learning. In the publications of the third protagonist of this paper, this theme of demarcating experts from drivelers is prominent. Nicolaas Hartsoeker can be counted among the same generation of telescopists as Flamsteed and Picard, among others things working in the Paris observatory during the late 1680s. Moreover, he was a protégé of Christiaan Huygens, which establishes a biographical link in the Dutch chain of dioptrics I am discussing here.

Nicolaas Hartsoeker (1656-1725) was the son of a Remonstrant minister, who had chosen to study the Book of Nature rather than the Holy Scripture.[46]

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44 John Flamsteed, *The Gresham lectures of John Flamsteed*, ed. Eric G. Forbes (London: Mansell Information Publishing, 1975), 34-39 (Forbes' introduction).

45 Jean Picard, *Régistres des procès-verbaux de l'Académie Royale des Sciences*, Archives de l'Académie des Sciences, Paris, volume 9, 55r-59v; 110r; (a piece on mirrors is in Régistres 7, 149v-153v); Jean Picard, 'Fragmens de Dioptrique' in *Divers ouvrages de mathematique et de physique. Par messieurs de l'Académie Royale des Sciences*, published by Philippe de la Hire (Paris, 1693), pp. 375-412. John Flamsteed, *Gresham lectures*.

46 Biographical details are in Michiel R. Wielema, 'Hartsoeker, Nicolaas (1656-1725),' in *The dictionary of seventeenth and eighteenth-century Dutch philosophers*, ed. Wiep van Bunge et.al., 2 vols., Vol. I (Bristol:

He made his living as a lensmaker. He said he owed his passion for optics to Antoni van Leeuwenhoek. In 1674, together with a fellow student and assisted by Van Leeuwenhoek, he was the first to observe semen (it later provoked a priority dispute with Van Leeuwenhoek over the discovery of 'animaux spermatiques'). Early in 1677, Hartsoeker became acquainted with Christiaan Huygens, who had become very interested in the new microscopes. Hartsoeker initiated him into the art of producing the tiny lenses of Leeuwenhoekian microscopes.[47] In June 1678, Huygens returned to Paris and took Hartsoeker with him as an assistant of sorts. The Dutchmen made a great impression at the Académie with their microscopes and observations, but they would soon fall out. In August, Huygens published in the *Journal des sçavans* on the 'microscope brought from Holland' without even mentioning Hartsoeker's name.[48] Hartsoeker replied with a letter to the editor, who published only an extract after consulting Huygens.[49] A nasty trick to play on a subordinate! In 1679, Hartsoeker returned to his hometown of Rotterdam, married, and eventually went bankrupt as an instrument maker and wine merchant. In 1684 he took his wife to Paris, where he made instruments for the Académie and the observatory and supervised the glass production for some expeditions.[50] Hartsoeker would stay in Paris until 1698, when the rising cost of living and the uncertain flow of income forced him to return to Rotterdam again.

Towards the end of his stay in Paris, Hartsoeker had begun publishing books, a sign of his ambitions to elevate himself in the republic of letters. His first book was *Essay de dioptrique* in 1694, the title bearing witness to his principal occupation.[51] The book can be read as a careful effort to position the author as an experienced yet learned telescopist, to be distinguished from mere empirics on the one hand and unworldly philosophers on the other. In his dioptrics, Hartsoeker employed mathematics to teach the operation of telescopes. Those matters did need teaching, as is clear throughout the text. Hartsoeker repeatedly pointed out the fallacies of 'great men that argufy on

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Thoemmes Press, 2003), pp. 389-390; Michiel R. Wielema, 'Nicolaas Hartsoeker (1656-1725): Van Mechanisme naar Vitalisme,' *Gewina* 15 (1995): 243-261, on pp. 245-250.

47 See for example: Huygens, *OC8*, 58-61.

48 *Journal des sçavans*, August 15, 1678. Huygens, *OC8*, 96-97.

49 *Journal des sçavans*, August 29, 1678. The extract and Hartsoeker's original letter: Huygens, *OC8*, 98-103.

50 Jean Picard, Régistres 11: 114v, 115r-116v.

51 Nicolaas Hartsoeker, *Essay de dioptrique*. Par Nicolas Hartsoeker (Paris, 1694). Nicolaas Hartsoeker, *Proeve der Deurzicht-kunde, In het Frans beschreeven van de Heer Nicolaas Hartsoeker; en vertaald door A. Block* (Amsterdam, 1699). I have used the Dutch translation. I compared it with the French original and found it to be faithful and complete. Block employs a fine and very pure Dutch, which unfortunately has not become standard.

false principles', which could have been prevented had they known a little mathemathics.[52] His translator, Block, stressed this point in his preface to Hartsoeker's book. Block found the lucid, veracious, judicious *Essay* (as also the later *Principes de physique*) so important that he had translated it for amateurs of optics who did not read French or Latin. He observed:

It will be very easy for us nowadays to know for certain, according to our present knowledge, that we are still very far from observing in the Stars or even in the Moon, which is after all close enough to us, any particular things that have the least similarity to those that we perceive so distinctly with telescopes in the terrestrial globe; and also, that all such writers that have wanted to give us the slightest hope of doing so have indeed been misled and deceived in their conceived opinions. One would have to have an object-glass of 701 $^{1}/_{6}$ feet aperture, and with a focal length of 283,181,760 feet, making up approximately 15 semi-diameters of the terrestrial globe, in order to observe just one object in the Moon of 5 feet in diameter.[53]

A simple calculation was enough for Nicolaas Hartsoeker to show the fallacy of those writers. A lens of over 200 meters diameter – which would not even fit between the houses on both sides of the Kloveniersburgwal – did not exist and was simply unfeasible for anyone with the slightest knowledge of lens making. (And it still is; the largest refractor is only just over a meter in diameter – even the largest reflecting telescopes with a single mirror are only just over 8 meters.) Man will not see lunar inhabitants, and anyone who believed that the new instruments ameliorating the senses of seventeenth-century man would bring them to our eyes in the not-too-distant future did not know what he was talking about. Without the name being mentioned, Hartsoeker's target was clearly Robert Hooke, who, in the preface of *Micrographia*, had suggested as much.[54]

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[52] Nicolaas Hartsoeker, *Proeve*, p.107.

[53] Nicolaas Hartsoeker, *Proeve*, pp. 148-149. '*Dat men een Vérre-kyker zoude moeten hébben, van ontrént 15 halve-middellynen des Aardkloots, beneevens een voorwérp-glas van 701 1/6 voeten openings, om een voorwérp van 5 voeten Middellyns (Diametre.) in de Maan daar meede te beschouwen*. Het zal ons nu teegenwoordig heel gemakkelyk vallen, om zeekerlyk te kunnen weeten, dat wy, na onze teegenwoordige kénisse, nóch wél vérre daar van af zyn, om, in de Stérren, óf zélfs in de Maan, die noch al dicht genoeg by ons is, eenige byzondere zaaken te kunnen beschouwen, die eenige de minste over-een-komste hébben, mét zulke onderscheidingen als wy wél mét de Vérre-kykers op den Aardkloot gewaar wérden; als meede, dat alle zulke Schryvers wél deegelyk in hunne opgevatte meeningen zyn misleit en bedroogen geweest, die ons eenige de aldermiaste (sic) hoop dies-aangaande hébben willen geeven. Men zoude een voorwérp-glas moeten hébben van 701 1/6 voeten openings, en dat een Brandpunt hadde van 283181760 voeten, die ten naasten-by 15 halve-middellynen des Aard-kloots uitmaaken, om sléchts alléén een voorwérp in de Maan te bespiegelen (Observer.), dat 5 voeten middellyns hadde'.

[54] Robert Hooke, *Micrographia: or some physiological descriptions of minute bodies made by magnifying glasses with observations and inquiries thereupon* (London, 1665), preface. Jim Bennet, 'Hooke's instruments,' *London's Leonardo – The life and work of Robert Hooke*, ed. Jim Bennet et.al. (Oxford: Oxford University Press, 2003), pp. 63-104, on pp. 98-99.

To show that he knew what he was talking about, Hartsoeker demonstrated the figures he had given. Assuming that the eye, having an aperture of a quarter line, distinguishes a 5 foot object at a distance of 2865 feet, an aperture of $701\,^{1}/_{6}$ feet is necessary to distinguish it at 1,157,078,400 feet (presumably the distance to the Moon).[55] Referring to a table of apertures and focal lengths, Hartsoeker concluded that the objective ought to have a focal length of 283,181,760 feet, being about 15 semi-diameters of the terrestrial globe.[56] Combined with an ocular aperture of $701\,^{1}/_{6}$ feet, this made a telescope that brings an object 403,821 times nearer. In other words, the Moon would appear to be only 2865 feet away from us, assuming that no light rays are lost during the journey through space, sky and glasses. Note that this fragment reiterates my point about mathematical contemplation as manipulation. Hartsoeker constructed (on paper) a telescope that would make objects on the moon visible, going on to explain that the required parts were impracticable. To inquire into the properties of lenses is to construct the path of refracted rays, the image of point sources, etc., as we already saw with the 'ratio' of sines.

All this is found in chapter nine of *Essay de dioptrique*, which deals with 'the way to avail oneself properly of the glasses of telescopes.' Together with the preceding and the following chapter, this chapter gave proof of Hartsoeker's wide knowledge and experience in all things pertaining to telescopes and microscopes. In great detail, he told his readers how to make, configure and apply lenses, and in addition explained why it had to be done in that way – for example, 'That the telescopes that are put together from two convex-ground glasses are the best of all, and for what reason'.[57] In doing so, Hartsoeker not only paraded his mastery of glass-works, but also his proficiency in mathematics. (Ill. 9)

The *Essay* thus reflects Hartsoeker's life up to the early 1690s. One can read the *Essay* as a resumé, the more so because its contents are not restricted to the exposition on optical instruments. The scope is much wider than the title suggests, as *Essay de dioptrique* places dioptrics in a broad natural-philosophical context, founding it on a deep layer of matter theory and cosmology. The *Essay* is the first instance in which Hartsoeker presented his conception of a universe built from two elements, which he further elaborated in his *Principes de physique* (1696) and later publications. In this sense, the *Essay* can also be read as an application for entry into the world of natural philosophy. It bore fruit:

55 Nicolaas Hartsoeker, *Proeve*, pp. 149-150.

56 Nicolaas Hartsoeker, *Proeve*, p. 147.

57 Nicolaas Hartsoeker, *Proeve,* p. 154. '*Dat de Vérre-kykers, die van twee ból-gesleepene glaazen* (Verres convexes.) *zyn te zaamen-gezét, de béste van allen zyn, en uit wat reede*'.

Ill. 9. Hartsoeker's own selenography, underlining the quality of his instruments as well his observing eye and mind. He depicted the Moon upside-down compared to Hevelius and Riccioli (and modern photographs). His nomenclature followed Riccioli, as a homage to the great astronomers. However, he changed the names the large 'seas', calling them 'woods'. Riccioli's 'Sea of Tranquility' thus became the 'Sixth Wood', surrounded by the craters 'Possidonius', 'Cassini' and 'Plinius'. Nicolaas Hartsoeker, *Proeve*, etching betwixt pp. 170-171.

in 1699 Hartsoeker was elected a member of the Académie and in 1704 of the new Berlin Academy of Sciences. His name spread; Czar Peter, visiting the Dutch Republic, wanted to meet him and offered him the chair of mathematics in St Petersburg. (In return for Hartsoeker's willingness to come to Amsterdam to instruct Peter, the magistrate financed a small observatory for him at the Amsterdam bastion). After Peter, Johann Wilhelm, Elector of the Paltz, came to see Hartsoeker and persuaded him to assume the office of first mathematician and honorary professor of philosophy at Heidelberg in 1704. The last years of his life he spent in Utrecht, continuing to publish on 'physique' (against the Newtonian system in particular).

Hartsoeker successfully transformed himself from telescopist to natural philosopher, which was surely no small feat. His expertise in dioptrics gained him access to the republic of letters as an instrument maker and adviser, but also as an author, for it gave him a topic on which to publish and elaborate in his first book. Hartsoeker performed this switch from skills to ideas by means of mathematics. In light of the preceding discussions of Descartes' and Huygens' dioptrics, it should not be surprising that this was possible. Mathematics formed a bridge between material and intellectual action; or rather, in mathematics these two were inseparable. A distinction between them can only be made on the basis of the stated (or implicit) goals of the expositions. Hartsoeker's (as well as Flamsteed's) complaints about the irrelevance of dioptrical writings to dioptrical practice make precisely this point.

Grinding dioptrics into natural philosophy

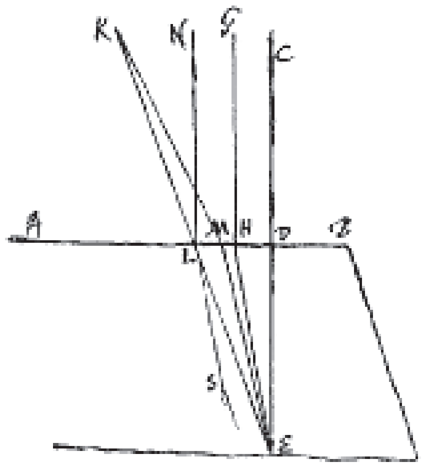
The fact that Hartsoeker could use this transfer within mathematics not only to move up from 'mathématicien' to 'géomètre' but also to enter the domain of natural philosophy suggests that natural philosophy contained an aspect of mathematics – or had least had recently acquired one. No student of the history of science will be surprised that this was indeed the case. In the hands of Descartes, Newton and the like, mathematics had become the avenue for a prominent school in natural philosophy, with *more geometrico* as the royal road to knowledge of the world. However, the traditional narrative of the mathematization of the world in the 'Scientific Revolution' suffers in my view from an expressly Platonic conception of mathematics and mathematization which obscures the historical developments that resulted in the reign of mathematics. Mathematics is understood on this view as consisting of abstract ideas that can be 'applied' to things. Application is of course a very troublesome concept. Historically it is a by-product of nineteenth-century ideological discussions about 'pure' mathematics – starting in the Enlightenment – and, more important, political and institutional discussions about education, organisation and the like. It is ahistorical to speak of 'application' when dealing with seventeenth-century mathematics. I think it is more fruitful and historically more apt to speak of mathematization as the production of mathematics in new domains, involving transfer of practices from other domains in which mathematics is already practised. These can be knowledge domains, or domains of crafts, but also social domains, institutional domains. The creativity of introducing mathematical practices in new domains then consists of ingeniously appropriating tools and methods developed elsewhere. And appropriating, as we all know, is a form of creating. Mathematics lent itself perfectly to such transfers, for, as we have seen, it constituted a common ground for divergent activities and groups.

Another point that classic history of science usually ignored is that mathematics was heterogeneous. If you look at the domains in which things mathematical were practised, you will see that a single, bounded field did not exist. Already on the level of the general word we have encountered the distinction between 'mathématique' and 'géométrie'. In the seventeenth century, a wide variety of activities existed that can be called mathematical, and were so called, of which the mutual connections are not self-evident: counting and reckoning, constructing and measuring, stargazing and mirrormaking, encryption and analysis. But this list also included philosophising, as witnessed in Molyneux's praise of Descartes' *Meditations* first of all for its mathematical character.[58] This leads to the conclusion that mathematics as such was heterogeneous, and that historical caution should be employed when lumping together all kinds of mathematical activities into a 'universe of precision', a mechanisation of the world-picture and so on.

I will conclude this essay by giving an example of what I have in mind with a historicised narrative of mathematization. Or, I should say, another such narrative, for Hartsoeker offers us an example of the social move from mathematics to natural philosophy. The example is Huygens' sequel to his theories of lenses and telescopes, his wave theory of light, which grew out of his stranded project of designing a perfect telescope. Its roots lie in a plan he drew up for a treatise on dioptrics in which he first considered the cause of refraction, and mentioned for the first time the strange refraction of Iceland crystal – the problem that would kindle his specific conception of light waves.[59] The point of this example is that it shows how mathematization was realised, not by somehow mathematically contemplating the nature of the world, but by transferring practices from one domain to another, from the dioptrics of lenses to the natural philosophy of the nature of light and the cause of refraction. Mathematization of the physics of light was not so much a kind of mathematical contemplation of ethereal corpuscles and the like; some kind of mathematical philosophising. Instead, there was much more *doing* involved: tinkering with mathematical objects, using expertise, skills and

[58] René Descartes, *Six metaphysical meditations; wherein it is proved that there is a God. And that man's mind is really distinct from his body. Written originally in Latin by Renatus Des-Cartes. All faithfully translated into English, with a short account of Des-Cartes' life. By William Molyneux* (London, 1680), translator's preface.

[59] Christiaan Huygens, *Codices Hugeniorum* (Leiden University Library), *Hug2*, 188r-188v. Fokko Jan Dijksterhuis, *Lenses and waves*, pp. 109-112.



Ill. 10. A sketch by Huygens of rays refracted in Iceland Crystal. Perpendicular ray GH is refracted towards E, whereas the oblique ray KL traverses unrefractedly. *Œuvres complètes* 19, n 10.

strategies developed in the existing field of geometrical optics. More important, mathematization provided the conceptions of valuable knowledge that lay behind these efforts. The result was an optics in which the nature of light was central and the goal was to explain phenomena by deriving the laws of optics.

Strange refraction in Iceland crystal comes down to rays of light not being refracted according to the sine law of refraction. In particular, a perpendicularly incident ray is refracted from the normal (Ill.10). This posed a problem for Huygens' understanding of light waves, which drew on a theory formulated by his Paris acquaintance, Father Ignace Gaston Pardies. Pardies' theory presupposed that rays are always normal to waves. If a perpendicularly incident ray is refracted, however, this requirement is violated, as Huygens noticed in his manuscript notes (and continued to puzzle over). Aside from the question of why he thought this was a problem, and why he wanted to solve it, what is fascinating is the *way* he tried to solve it. Huygens analysed the behaviour of rays in Iceland crystal by taking Descartes' analysis of ordinary refraction and extending it to strange refraction. (While ordinary refraction affects the perpendicular component of an incident ray but does not alter the parallel component, strange refraction adds a constant measure to the parallel component.) What is interesting about this is not so much that Huygens borrowed a theory that he had, a little earlier, explicitly rejected, and not that he considered the behaviour of rays rather than of waves, even though strange refraction was a problem of waves. What is interesting is that we see here what mathematical thinking or the 'application' of mathematics in early modern times might mean. We see that Huygens appropriated a piece of mathematics – Descartes' analysis of refraction – and employed it in a new context – Iceland crystal.

This is important, because it sheds light upon the next step of Huygens' struggle with strange refraction.[60] 'Struggle' is perhaps putting it too strongly, for once he conceived of a new understanding of ether waves and their propagation, the solution to the problem of strange refraction presented itself almost effortlessly. Huygens supposed waves of light to propagate in the crystal at different speeds in different directions (a violation of the presumed norm), thereby resulting in ellipsoidal waves. Once the parameters are set properly, the refraction of the perpendicular ray follows immediately. The refracted ray is indeed not normal to the wave, but this no longer posed a problem, thanks to Huygens' new wave principle. What is interesting about this solution is that it was not so much about ether, corpuscles and the crystal, but more a clever tinkering with circles and – eventually – ellipses. Leafing back through Huygens' manuscripts, we see that his new conception of wave propagation likewise was a matter of mathematics.[61] It came up when he was tackling the rather technical problem of caustics. What he had done was to transfer his ideas on linear motion and impact to ether waves, and reduce the propagation of those waves to one defining characteristic: velocity. In other words, he again borrowed some mathematics from another context to attack a particular problem.

We now have a better idea of what mathematization in the seventeenth century might be. It is interesting to notice that Huygens did not so much bother about nature – let alone the universe – or about the mechanistics of ether motions; what he bothered about was the mathematics of the problem and he wanted to get the mathematics right. Find out the relevant domain of mathematics (rays, waves, etc.), and then determine how to phrase the matter precisely (components, velocities…). Huygens pursued the natural philosophy of light in much the same way as he pursued the mathematics of dioptrics: he tinkered with geometrical figures. In other words: manipulating objects was a way of contemplating nature.

I have tried to show how, in the hands of Descartes, Huygens and Hartsoeker, dioptrics dealt with both the way of instruments and the way of ideas, of manipulation and of contemplation, and was hence an endeavour where 'mathématique' and 'géométrie' are hardly distinguishable. I have also suggested that this held for mathematics in general, the problem of the entwinement of manipulation and contemplation being inherent to early modern mathematics.

60 Fokko Jan Dijksterhuis, *Lenses and waves*, pp. 161-172.
61 *Hug9*, 38r-48v.

In this way dioptrics and mathematics offer a fine instance of the inventive intersections that have inspired this book. Finally, I have sketched how dioptrics could be a route to natural philosophy – intellectually in the case of Huygens, socially in the case of Hartsoeker – thus suggesting a historicised view of the mathematization of the (intellectual and material) world in the early modern period. This historicised view is much less one-dimensional than the classic narrative of a 'universe of precision', because it turns mathematics into a heterogeneous affair in which all kinds of people and practices were running all over the place – a motley crew that confused even contemporaries like poor Le Tellier.

Primary sources

Beeckman, Isaac, *Journal tenu par Isaac Beeckman de 1604 à 1634*, ed. C. de Waard, 4 vols. (Den Haag: Martinus Nijhoff, 1939-1953).

Descartes, René, *Six metaphysical meditations; wherein it is proved that there is a God. And that man's mind is really distinct from his body. Written originally in Latin by Renatus Des-Cartes. All faithfully translated into English, with a short account of Des-Cartes' life. By William Molyneux* (London, 1680).

Descartes, René, *Oeuvres de Descartes*, ed. Charles Adam and Paul Tannery, 2nd edn., 11 vols. (Paris: Vrin, 1974-1986).

Flamsteed, John, *The Gresham lectures of John Flamsteed*, ed. Eric G. Forbes (London: Mansell Information Publishing, 1975).

Hartsoeker, Nicolaas, *Essay de dioptrique*. Par Nicolas Hartsoeker (Paris, 1694).

Hartsoeker, Nicolaas, *Proeve der Deurzicht-kunde, In het Frans beschreeven van de Heer Nicolaas Hartsoeker; en vertaald door A: Block* (Amsterdam, 1699).

Hooke, Robert, *Micrographia: or some physiological descriptions of minute bodies made by magnifying glasses with observations and inquiries thereupon* (London, 1665).

Huygens, Christiaan, *Codices Hugeniorum* (Leiden University Library).

Huygens, Chrisiaan, *Traité de la lumiere. Où sont expliquées les causes de ce qui luy arrive dans la reflexion, & dans la refraction. Et particulierement dans l'etrange refraction du cristal d'Islande, par C.H.D.Z., avec un discours de la cause de la pesanteur* (Leiden, 1690).

Huygens, Christiaan, *Oeuvres complètes de Christiaan Huygens*. Publiées par la Société Hollandaise des Sciences, 22 vols. (Den Haag: Martinus Nijhoff, 1888-1950).

Huygens, Constantijn, *De briefwisseling van Constantijn Huygens, (1608-1687)*, uitgegeven door J.A. Worp, 6 vols. (Rijks geschiedkundige publicatiën. Grote serie; 15, 19, 21, 24, 28, 32) (Den Haag: Martinus Nijhoff, 1911-1917).

Kepler, Johannes, *Dioptrice seu demonstratio eorum quae visui & visibilibus propter conspicilla non ita pridem inventa accidunt* (Augsburg, 1611).

Kepler, Johannes, *Gesammelte Werke*, ed. Walther von Dyck and Max Caspar, 17 vols. to date (Munich: Beck, 1937).

Mersenne, *Quaestiones celeberrimae in Genesim* (Paris, 1623).

Mersenne, *La vérité des sciences* (Paris, 1625).

Mersenne, Marin, *La correspondance du P. Marin Mersenne*, ed. P. Tannery and C. de Waard (Paris: Editions du CNRS, 1933).

Newton, *Opticks or a treatise of the reflections, refractions, inflections & colours of light. Based on the fourth edition, London 1730* (New York: Dover Publications, extended edition 1979).

Newton, Isaac, *Optical papers of Isaac Newton*, ed. Alan. E. Shapiro, 1 vol to date, Vol. I (Cambridge: Cambridge University Press, 1984-).

Picard, Jean, *Régistres des procès-verbaux de l'Académie Royale des Sciences*, Archives de l'Académie des Sciences, Paris.

Picard, Jean, 'Fragmens de Dioptrique,' *Divers ouvrages de mathematique et de physique. Par messieurs de l'Académie Royale des Sciences*, published by Philippe de la Hire (Paris, 1693), pp. 375-412.

11. Nature's oeconomy

Introduction

Simon Schaffer

At the end of 1630, Tuscany's superintendent of fortifications asked Galileo Galilei to intervene in a dispute between two rival engineers about flood defence methods in a local river. As Mary Henninger-Voss reminds us in the previous section's opening essay, Galileo liked using cannonballs to model nature's behaviour. The water dispute was a case in point. Galileo sent the Tuscan government a report on river management that compared water flow to the passage of cannonballs through a pipe. He used this ingenious mix of ballistics and hydraulics to establish his rights as 'censor, perhaps among the most useful and necessary office,' a judge of expert engineers and servant of the state.[1] In this section of our book, attention shifts towards such scenes of water management and territorial administration. The previous essays explored how texts and practices worked together in early modern European natural philosophy, mixed mathematics and craft enterprise. Our explorations travelled attentively between battlefields, libraries and workshops. Crucial here was the relation between contemplative knowledge of the created world and active transformation of its practical order. That relation might be one of distinction, with philosophical knowledge supposed separate from artful ingenuity, or it might be one of complex assimilation. Historians, no doubt, have inherited these models of distinction and assimilation. Rightful development of artful practice in company with potent understanding often depended on the support of ancient precedent – from Adamic Eden or Vitruvian Rome. And this development got its warrant and opportunity from the aid it might offer the newly aggressive enterprise of territorial administration cultivated by ambitious, militant and fiscal states.

So this next section of our book addresses fundamental problems of the relations between inquiry and invention in some important settings of sixteenth- and seventeenth-century western European public territorial enterprise. We examine the great water projects of the age, the construction of founts,

[1] Stillman Drake, *Galileo at work: his scientific biography* (Chicago: Chicago University Press, 1978), pp. 320-29.

channels, sewers, floating meadows and drained lands in the name of a kind of territorial regeneration. In his remarkable analysis of the relation between hydraulic engineering and absolutist states, Karl Wittfogel pointed out half-a-century ago the coincidence of the great canal programmes of early modern Europe, such as the Canal du Midi linking Atlantic with Mediterranean, and the emergence of 'governmentally encouraged commercial and industrial capitalism'. The eminent economic historian Jan de Vries judges that high grain prices in earlier seventeenth-century northern European lands 'inaugurated a flood of investment capital' in projects such as the Beemster lake drainage in North Holland and the reclamation of the east English fenlands. These were capital-intensive territorial enterprises that often drew on larger sums and more complex artifices even than those invested in long-range global trade networks.[2] The aim here is to show that in the major contests about changes in the land wrought by hydraulic engineering, new kinds of knowledge and technique were forged. Yet however innovative, protagonists of the hydraulic projects were helping themselves to rather traditional models of Nature's capacities: we are certainly not dealing in this section of our book with the simple application of some form of enlightened science to evident technological purposes. Rather, it was often claimed that through radical change in the order of Nature one could at last reveal Nature's true face. There was, in fact, an intimate relationship between any specific account of what Nature was like and accounts of who had the rights and the skills to manage it. We see, in these essays, how definitions of natural order accompanied attempts to assign head and hand their seemingly appropriate places in the social order.

The contributions to this section therefore focus on the management of the water systems as crucial sites for the ingenious management of drainage and transport, farming and commerce and at the same time for the making of social and natural knowledges. Katherine Rinne describes successive sixteenth century projects to overhaul Rome's water supply. In the Eternal City of the High Renaissance past traditions as well as local political and technical conflicts much affected the details of aqueduct, fountain and channel designs. We then examine two of the greatest public drainage projects of the first half of the seventeenth century. Eric Ash analyses the notions of nature and its powers at stake in the drainage of the Great Fens while Alette Fleischer explores the religious, practical and social interests involved in the drainage of the Beemster. Finally, Chandra Mukerji considers the ways in which expertise and authority were established in the large-scale mid-seventeenth century programme to

[2] Karl Wittfogel, *Oriental despotism: a comparative study of total power* (New Haven: Yale University Press, 1957), p. 32; Jan de Vries, *The economy of Europe in an age of crisis 1600-1750* (Cambridge: Cambridge University Press, 1976), pp. 37-38.

construct the Canal du Midi. What also emerged here was a new so-called 'science of waters', first among those geometrically expert Galilean scholars in central and northern Italy who would contrast their formal analysis of water velocity with what they condemned as merely empirical tactics of state-employed engineers. Other territories emulated and adapted the strategy, as in the Dutch institutionalisation of academic teaching and official regulation of water management.[3] It was never entirely obvious how to distribute trust between academic disciplines in hydraulics and the work of state advisors and of indigenous populations. The development and execution of such water systems therefore offer a peculiarly illuminating site where rival claims of expertise, of geometrical ordering and of traditional skill were debated and applied.

These were all vast schemes, involving entire cities, provinces and states in their planning and execution. Debate and dispute were correspondingly intense and large-scale. In Renaissance Rome, Rinne shows, contests for power between the papal administration and the council of the City were worked out through the accreditation of rival advisors on water planning. Penalties for failure were high: one Roman architect reportedly died in jail after fomenting major conflicts between expert masons, surveyors and patrons. In the projects for the Canal du Midi, the Toulouse city council was fierce in its criticisms of the ambitious hydraulic plans of the entrepreneurial administrator Pierre-Paul Riquet. In a remarkable publication of 1667, rival advice on the canal route from Riquet and from the city's own expert were juxtaposed in facing columns of print. Often the fights spilled over from book to field. The conflicts around English fen drainage notoriously became involved in nation-wide civil war. Royal backing for alliances of wealthy lords and drainage engineers helped alienate large numbers of eastern English commoners from the monarchy. The King might tell Parliament in 1641 that water management in Fenland would bring 'as great a profit to this commonwealth as the whole province of Holland and Zealand in the Low Countries now do,' but 'the very rude kind of people' violently protested against so-called 'improvements'.[4] On the other hand, polemical interests invested in these projects were responsible for making new forms of knowledge and expert skills. As Mukerji reminds us, energetic controversy was often more likely than equable consensus to prompt

[3] C.S.Maffioli, *Out of Galileo: The science of waters 1628-1718* (Rotterdam: Erasmus, 1994) and Maffioli, 'Italian hydraulics and experimental physics in eighteenth-century Holland,' in *Italian scientists in the Low Countries in the XVIIth and XVIIIth centuries*, ed. C.S.Maffioli and L.C. Palm (Amsterdam: Rodopi, 1989), pp. 243-75.

[4] Brian Manning, *The English people and the English Revolution* (Harmondsworth: Penguin, 1978), pp. 140, 148.

innovative technique and ingenuity. Indeed, these early modern water projects frequently saw the formation of novel and potent alliances keen to weld engines, maps and workforce to profitable purposes. Fleischer points out that Beemster stakeholders' alliances linked merchants with administrators and scholars in newfangled close-knit networks where reliable information and verifiable skill were at a premium.

Because stakes were high and interests evident in these schemes, their histories let us examine how relations between head and hand were worked out in practical enterprises. How exactly could one ever make, observe or indeed undermine expertise and trustworthiness? One classical term helped early modern Europeans make sense of what was at stake in these kinds of territorially more extensive applications of reliable knowledge and more effective cultivation of ingenious art: 'oeconomy' and its cognates. Classical authorities distinguished 'oikonomia' as household stewardship from public enterprises of commerce and profit. The model of state regulation that saw the prince as steward of the state's domestic order reckoned oeconomy crucial to virtuous management of the political body. Mukerji points out that this analogy between local estate stewardship and more expansive territorial government helped underwrite the important claim that what could be shown to work locally at the scale of an estate could therefore be supposed to work on a much grander scale. The oeconomic analogy was therefore a kind of politico-commercial solution to the problem of induction. Importantly for our interests in the relations between established knowledge and practical arts, 'the decisive category for defining the kingdom became that of territory,' as the engineering historian Hélène Vérin has put it. 'A true economy' focused on the regulation of officers' training, practice and knowledge.[5]

Oeconomy described the means through which the administrator's knowledge could be put to effect in management of ordered terrains. The new Bourbon regime of Henri IV found important arguments for such management in the massive work of the Huguenot writer Olivier de Serres, *Theâtre d'agriculture et mesnagement des champs*. Mukerji explains that Colbertiste strategies of the 1660s, when the Canal du Midi was projected, shifted somewhat from a imaginary restoration of the original divine plan towards an ideology of a new empire under the dominion of the Sun King. Rival political programmes much affected the execution of these great schemes. Thus, in the case of Fen drainage, the appearance of 'oeconomy' as a term in seventeenth-century English is chronologically suggestive, since it matches rather exactly the most dramatic

[5] Hélène Vérin, *La gloire des ingénieurs: l'intelligence technique du XVI^e au XVIII^e siècle* (Paris: Albin Michel, 1993), pp. 185, 204-5.

crisis in the financial and political basis of the Kingdom. Long used solely for domestic stewardship, we witness the sudden use of 'oeconomy' as public fiscal administration, social regulation and frugal management only from the cataclysmic years of the mid-seventeenth century. Ash explains how drainage schemes and models of the welfare of the Commonwealth were peculiarly intertwined in the period of the Civil Wars and the Republic. Oeconomy also now began polemically to be used to describe the divine management of creatures and of Nature itself.[6]

Such usages and polemics developed throughout the new European state system. This kind of territorial management in Cameralism and in the work of administrators and natural philosophers in the German lands, for example, was peculiarly concerned with the tasks of running mines and estates where water systems were crucial enterprises for state income and territorial welfare. These administrators agreed that 'oeconomy is a practical science,' as a 1744 oeconomy handbook taught, 'wherein the wisdom, prudence and art of nearly all learned sciences are applicable to the end of rightful concerns for provisioning and economy'. Within this enterprise of pumps, mine drainage, water supply and hydraulic systematics, in which eminent court advisors from Leibniz to Goethe all took part, the disciplines of 'Wasserwirtschaft' and 'Wasserhaushalt' occupied central places. The terms are better translated as 'water management' and 'water husbandry', a vocabulary of more customary and territorial significance than the erudite term 'hydraulics' might imply.[7]

The relation between expert knowledge and cunning art could therefore be understood, in part, by relating the magistrate's oeconomy of territorial order in which experts would be hired to act, and the divine oeconomy of nature of which experts would be employed to make sense. The principles of Nature's oeconomy could themselves be derived from Nature understood as a source of authority for human knowledge. Or they might be directed at overcoming Nature understood as a source of resistance to human purpose. The principal historian of the eighteenth-century French engineering corps, Antoine Picon, points out this paradox of Nature's oeconomy: 'the engineers of Ponts-et-Chaussées were daily confronted by a hostile Nature against which they had to

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[6] Keith Tribe, *Land, labour and economic discourse* (London: Routledge, 1978), pp.80-85; *OED* s.v. 'economy'.

[7] G.H.Zincke, *Allgemeines Oeconomisches Lexikon* (Leipizig, 1744), in Myles Jackson, 'Natural and artificial budgets: accounting for Goethe's economy of nature,' in *Accounting and science: natural inquiry and commercial reason*, ed. Michael Power (Cambridge: Cambridge University Press, 1994), pp. 57-80, on p.70. For Leibnizian water management schemes in the 1680s, see Jürgen Gottschalk, 'Technische Verbesserungsvorschläge im Oberharzer Bergbau,' in *Gottfried Wilhelm Leibniz*, ed. Erwin Stein and Albert Heinekamp (Hannover: Schlüter, 1990), pp. 62-71. Leibniz's schemes for the water supply for the palace at Herrenhausen are reproduced in ibid, pp.127 and 148-9.

struggle to ensure the permanence of their works…Yet the engineers also saw there a principle of activity, a source and norm of behaviour for humanity'. This mattered especially in systems of territorial communication and agronomy. 'It seemed as if Nature turned its own forces against itself. Separating humans by means of Nature's contours, it nevertheless at the same time provided them with the means of reunification'. Because Nature thus worked to legitimate engineers' savvy while countering spatial engineering with recalcitrant resistances, the precise definition of Nature's oeconomy was always also a definition of the rights of those who should be charged with its regulation.[8]

One way of defining these rights was therefore to build putatively 'natural' models of the systems in question. In the Beemster schemes, as Fleischer reports, local mill-masters constructed models to show their skills to the regulatory board of investors. The board then called other expert advisors to interpret and judge the adequacy of these model schemes. Similarly, Riquet commissioned a small-scale model of his canal project on his own Languedoc estate, with a view to convincing his powerful patron of its plausibility and his own authority. Mukerji explains how the administrative analogy between estate and realm helped underwrite this putative inference from a miniature estate-scale model to a vast hydraulic project. So specific accounts of Nature's capacities and of the social order were designed to legitimate specific powers vested in expertise. The subjection of Nature to number, weight and measure was a crucial component of the ideology and the practice of the great water schemes. The controversies about Fen drainage considered by Ash are perhaps the clearest example. Those who resisted drainage plans represented Nature as pristine and self-regulatory, threatened by overweening artifice. Those who backed the most ambitious drainage schemes countered with a model of Nature as in need of efficient and technical direction, thus subject to the exacting ingenuity of the projectors and their tools. Indeed, one important claim in Ash's analysis is that these rival models of Nature were in play not only in fights about whether drainage should take place, but about how it should be conducted. To rely on widening existing river channels through the Fens was precisely to appeal to the virtues of Nature's original disposition; to urge, as did some of the incoming Dutch engineers, the need to cut new long drains straight through the marshes was to account Nature as a system in need of restorative ingenuity. Only by the application of skill and technique, so it was argued, could the primitive powers vested in Nature be corrected and restored.

[8] Antoine Picon, 'L'Idée de nature chez les ingénieurs des ponts et chaussées,' in *La nature en révolution 1750-1800*, ed. Andrée Corvol (Paris: L'Harmattan, 1993), pp. 117-125 on pp. 117-119.

If Nature thus resisted human purposes because humanity had fallen and left Eden forever, it might equally be possible to re-enter Paradise by mastering the capacities placed in Nature by its wise Author. Significantly, the same kind of elemental discourse was present in classical authorities in engineering and architecture. The eighth book of Vitruvius' work on architecture, as example, devoted entirely to the location, analysis and channelling of water, started with an outline of the elementary principles of Nature and the claim by 'naturalists, philosophers and priests that all things depend upon the power of water'.[9] Not surprisingly, learned scholars would scour classical sources for evidence of past ingenuity and for precedents for ancient waterworks, aqueducts, gardens or urban plans. Rinne clearly shows how Renaissance Roman engineers and projectors combined their philological interpretations of sources such as Vitruvius and the first century water engineer Frontinus with up-to-date urban fieldwork in the water networks of the City. Ancient marks of Tiber flood heights, for example, were used as informative signs for the design of new fountains and pipes in the 1570s. Similarly, according to Fleischer, Dutch experts such as Simon Stevin or Jan Pietersz Dou could show their expertise simultaneously as masters of classical tradition and as innovators in large-scale technical schemes. This kind of 'conservative invention', as Fleischer calls it, was a way of combining the continuing social power of precedent with the needs of investors and patrons for locally effective and plausibly profitable enterprise.

Appeal to precedent and to Nature's primordial capacities was thus a very polemical move. The fundamental principles of Nature's capacities, so it was argued, could be revealed through the ingenious manipulation and reorganisation of productive forces. Art showed what Nature truly was. This was not a strategy limited to hydraulic oeconomy – it was present in the entire programme for improved agricultural oeconomy that characterised early modern European societies. As historians of natural history have taught us, naturalists won their power in society through showing their role in this oeconomy. The pre-eminent eighteenth-century naturalist Carl Linnaeus, a protagonist of this enterprise, thus insisted that 'our own economy is nothing but knowledge about nature adapted for man's needs'. He firmly linked naturalists' authority with their oeconomic mastery of the elements which composed Nature: 'the science that teaches us to use natural things through the Four Elements for our use is called Economics'.[10] The natural philosophy of the four

[9] Vitruvius, *Ten books on architecture*, ed. Henry Langford Warren (Cambridge, MA: Harvard University Press, 1914), 226.
[10] Lisbet Koerner, *Linnaeus: nature and nation* (Cambridge, MA: Harvard University Press, 1999), pp. 100-104; Emma Spary, 'Political, natural and bodily economies,' in *Cultures of natural history*, ed. N. Jardine, J.A. Secord and E.C. Spary (Cambridge: Cambridge University Press, 1996), pp. 178-96.

elements proved peculiarly apt for the practical drainage schemes considered in these essays. In a kind of 'alchemy of improvement', the reclamation of fens and bogs could be described as the ingenious transformation of water into earth. This kind of elemental transformation was present in agriculture too. English texts, such as *The science of good husbandry, or the Oeconomics of Xenophon* (1727), welded classical works of 'oikonomia' to contemporary philosophies of earth and water, thence deduced the right principles of management in family, farm and state. As the historian Keith Tribe points out, 'the argument characteristically orders itself round the traditional categories of such reflection: earth, air, fire and water'.[11] Agronomy might be understood as the extraction of surplus from otherwise passive earth by the manipulation of vital aqueous principles placed in the soil by a benevolent creator. Such elemental stories were tied to narratives of classical and scriptural authority. Agronomists found in the Bible the oeconomic principle that 'the vegetable tribes imbibe this unspotted mirror of divinity, this heavenly confection'. Such 'shining drops of summer dew' were 'transparent chests which contain a richer treasure than the mines of Potosi'.[12]

However seemingly atavistic, such enterprises had major political implications. As such a reference to the greatest of colonial mining enterprises reminds us, it is instructive to think of these forms of oeconomy as colonial programmes, the engrossing of new territory and the expropriation of existing skills and use-rights in the name of production and providence. Though these essays focus on western European cases of hydraulic management, it is important to emphasise that the complex interaction between public regulation of the realm, providential order in Nature and the virtuous disposition of bodies dominated the early modern construction of colonial natural history and commerce. We see this well in the complex relation between experts and indigenous tradition. Naturalists and engineers might try to display the lands they proposed to drain and manage as Edenic because they offered paradisiac regeneration and because it was possible to imagine them as deserted, so ripe for possession. Such uses of the past, as we see in detail in this section, functioned as ways of discriminating between the erudition and morality of licensed experts and the supposedly hidebound practices of autochthonous vulgarity. Yet in fact the oeconomy of water management and improved agronomy very often relied on already present and certainly effective practices cultivated by adept inhabitants. As Ash rightly emphasises, for example, Fenland was neither self-evidently deserted nor unproductive and Fenlanders' techniques were

[11] Tribe, *Land, labour and economic discourse*, pp. 60-66.

[12] John Dove, *Strictures on agriculture* (London, 1770), in G.E.Fussell, *Crop nutrition: science and practice before Liebig* (Lawrence, Ka.: Coronado Press, 1971), pp. 132-33.

often indispensable to successful hydraulic schemes. Comparable problems arose in the colonies. When the great Dutch administrator and naturalist Hendrik van Reede prepared his celebrated *Hortus malabaricus* (1678-1693), he freely acknowledged his dependence on the local knowledge of low-caste indigenous physicians and collectors, and represented the oeconomy of Malabar forests as though 'cultivated by the careful hand of some gardener and planted in a very elegant order'. It is interesting to reflect on how prior Dutch experience of land reclamation and geometrical layout affected such visions of colonial nature. In similar terms, English officers in plantation Ireland reckoned that fenland drainage and rational oeconomy might turn a barren land into paradise. 'Out of the economics of Eden', the environmental historian Richard Drayton argues, 'had come an ideology of development'.[13]

Enlightenment savants, often hired as managers and advisors of the water oeconomy, were fully implicated in this newfangled ideology. In 1776, in the wake of very fierce controversies about the construction of a new state-sponsored navigation canal in Picardy, the eminent savants d'Alembert, Condorcet and Charles Bossut told their patrons and allies to 'expect nothing from the narrow-minded practitioner lacking in principles and driven by a blind rage, who hastily puts together several facts and is then unable to explain their differences. There are no sciences without reasoning nor science without theory'. 'Theory' began to appear as a keyword for the state's advisors keen to show their authority over such large-scale hydraulic and economic projects.[14] A crucial implication of the cases presented here is that in the same enterprises that sought to husband the oeconomy we also see efforts polemically to efface the very sources of artisan experience and customary tradition on which these enterprises nevertheless decisively depended. This is how Nature's oeconomy offered obstacles, social and physical, to be overcome by knowledge and art, yet also provided resources, political and elemental, to help that overcoming.

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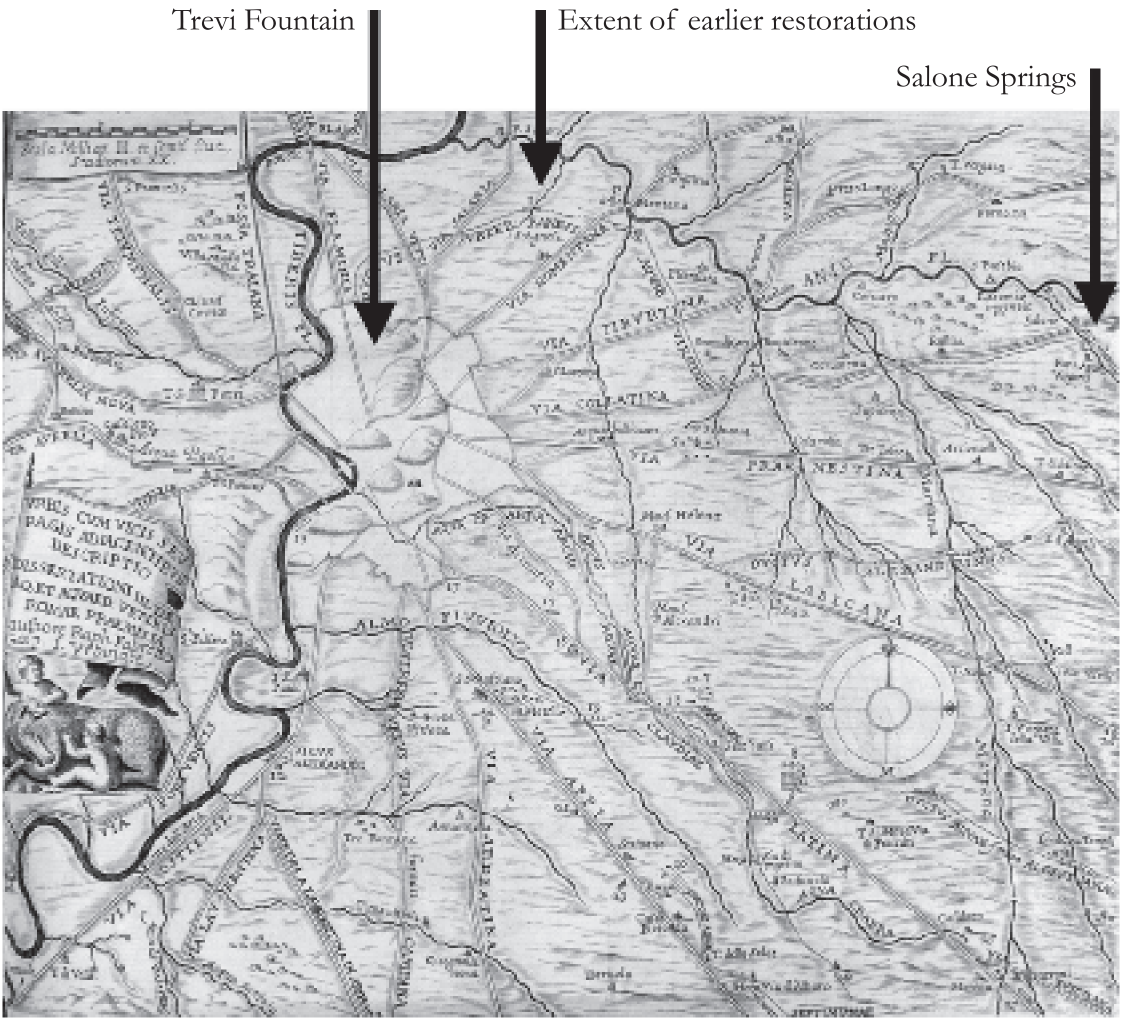
[13] J.Heniger, *Hendrik Adrian van Reede tot Drakenstein and Hortus Malabaricus: a contribution to the study of Dutch colonial botany* (Rotterdam: Balkema, 1986); Richard Grove, 'Indigenous knowledge and the significance of south-west India for Portuguese and Dutch constructions of tropical nature,' in *Nature and the Orient: the environmental history of south and southeast Asia*, ed. R.H.Grove, V. Damodaran and S. Sangwan (New Delhi: Oxford University Press, 1998), pp. 187-209, on pp. 199-200; Richard Drayton, *Nature's government: science, imperial Britain and the improvement of the world* (New Haven: Yale University Press, 2000), pp. 50-59.

[14] Pietro Redondi, 'Along the water: the genius and the theory: d'Alembert, Condorcet and Bossut and the Picardy canal controversy,' *History and technology* 2 (1985), pp. 77-110, on p.91.



The Acqua Vergine flows from the springs at Salone to the Trevi Fountain in Rome. Earlier restorations completed under Nicolas V and Sixtus IV, only extended as far as the area between Via Salaria Vetus and Via Salaria. Rafaello Fabretti, *De Aquis et Aquaeductibus Veteris Romae* (Rome: 1680), Map 3; provided courtesy of The Burndy Library, The Dibner Institute for the History of Science and Technology.

Between precedent and experiment: restoring the Acqua Vergine in Rome (1560-70)

Katherine W. Rinne

Among the important engineering projects that were undertaken in Rome during the late-sixteenth and early-seventeenth centuries were three proposals to restore and build aqueducts. The scale of these projects was enormous, yet all three were implemented and they had a profound effect on the city. They not only spurred urban growth and improved public health with a reliable and abundant water supply, but also, they shaped new modes of urban and territorial administration and helped to re-establish the joint temporal and spiritual hegemony of Rome and the Church as the centre of Christianity during the Counter Reformation. The first of these projects was a restoration of the ancient Aqua Virgo, by then called the Acqua Vergine, carried out between 1560 and 1570. This restoration was initiated by Pope Pius IV (1559-65) and completed under Pius V (1566-72). Pope Sixtus V (1585-90) sponsored the Acqua Felice between 1585 and 1587. That aqueduct tapped the springs of one ancient aqueduct, the Aqua Alexandrina and linked portions of the restored channel of another, the Aqua Marcia, with wholly new construction. The Acqua Paola, built between 1607 and 1612 under Pope Paul V (1605-21), reused the springs and followed along the course of the ancient Aqua Traiana using almost entirely new construction.

The sponsors and the persons that they hired to carry out the project (most of whom were architects) relied on ancient precedent to identify water sources, to find salvageable structures and materials, to determine the routes that any new construction would follow and to choose building materials and techniques. Precedent served as a kind of broad brush that outlined a basic strategy for constructing the aqueducts. Distributing the water was another matter, since little of the ancient distribution system within the city walls still survived in the sixteenth century. Therefore, many of the details relating to surveying, building and administering such a system had to be 'rediscovered' or developed by the varied group of 'experts' who designed and built the conduits and fountains of the first of the aqueducts, the Acqua Vergine. Most often, this involved learning what to do on site through analysis and experiment.

Over time a situation developed that allows us to sketch an interesting history of expertise. Precedent and experiment mingled in Rome to form hybrid methods of design and construction, while the social definition of an 'expert' followed a different course than the process of obtaining practical experience.[1] As we will see, the label 'expert' proved to have a rather local character, reserved for individuals with local connections rather than people who had obtained reputations as hydraulic engineers elsewhere. Further, criteria by which these 'experts' attained their status tended either to be text-bound or related to the design and construction of individual buildings and monuments rather than infrastructure projects. 'Experts' wrote or owned engineering treatises, published maps, designed buildings and sculpted statues, and thus brought little or no practical experience in hydraulic engineering with them. Consequently, the technological expertise needed to get the job done had to be won *in situ*, where it converged with the honoured presence of tradition and text-bound knowledge. It was this process that guided the transmutation of the ancient Aqua Virgo into the 'modern' Acqua Vergine.

Providing a reliable public water supply is always a complicated interplay between available technology, public policy, patronage and real estate development, and in early modern Rome, the situation was further complicated by the fact that Rome operated under polycentric spheres of power, with a level of mutual comity. The city had its own government, the Roman Council, which was controlled by noble families; and Rome was also the spiritual centre of the Catholic Church. Meanwhile, the pope (who was represented publicly by cardinals who carried out his wishes) was the most powerful person in Rome and he functioned somewhat as an absolute monarch.[2] Yet, he was not alone in developing water infrastructure projects. The Council, with its headquarters on the Capitoline Hill was also involved and was sometimes at odds with the papacy as each attempted to control, direct, intercept and divert water for personal gain and public benefit. In between, there were the powerful cardinals whose first allegiance was often to the cities, towns and estates of their own families.

Within this context, the plans developed by Pius IV and Pius V were implemented by a group of papal and civic officials with far-reaching powers who hired staff, tended bids, awarded contracts, levied and collected taxes, supervised construction work, developed standards, assigned water rights, regulated use and imposed fines. Since there was no formal training for engineers at this

[1] In her essay in this volume, Alette Fleischer argues that the interaction between precedent and experiment gave rise to 'conservative invention'.

[2] Laurie Nussdorfer, *Civic politics in the Rome of Urban VIII* (Princeton, NJ: Princeton University Press, 1992), p. 44-47.

time, there were no precise standards for choosing someone to direct this project, which was entirely unusual both in its program and scale. Although architects were most frequently selected to oversee the various phases of work, 'expertise' was judged on criteria that ranged from writing (or perhaps simply owning) engineering treatises, publishing maps, designing and constructing buildings, or even the ability to make sculptures. These 'experts' and their assistants then took on the responsibility to survey the routes, make models and drawings, design fountains, as well as the conduits and related infrastructure necessary to deliver water to them, and to test water pressure as the work progressed.

The first half of this essay addresses the struggles that took place between papal and civil authorities to maintain control of the process, all the while working with well established architectural and engineering precedents for building and maintaining aqueducts. The second half looks at the quotidian realities of how this varied group of 'experts' devised strategies to distribute water to public and private fountains throughout the Campo Marzio, the low-lying alluvial plain located in the bend of the Tiber River where the majority of Rome's population lived in the late-sixteenth century. Here, precedents were not readily available and had to be improvised, literally on the spot. Successful experiments brought immediate rewards, while failures could lead to fines or even to imprisonment.

The ebb and flow of Rome's water supply from Antiquity to the Renaissance

Roman aqueducts and fountains had been famed throughout antiquity for the abundance and salubrity of their waters, but of the eleven aqueducts that had served the ancient city only the Aqua Virgo still functioned in the cinquecento.[3] (Ill. 11 at the beginning of this essay) Built by Marcus Agrippa in 19 BC, the Aqua Virgo was only twentyone kilometres in length, and it ran underground along most of its route, from its source at the Salone Springs to the north-east of Rome. Because of the low level of the springs (only twenty-six meters above sea level), the aqueduct arrived in the city at a level of less than nineteen meters, which meant that it only served the lowest areas. Once inside the walls the channel emerged from the slope of the Pincian Hill in an area known in the mid-sixteenth century as *Capo le Case* (head of the houses), or

[3] For ancient aqueducts, see Thomas Ashby, *The aqueducts of ancient Rome* (Oxford: Oxford University Press, 1930); Harry Evans, *Water distribution in ancient Rome; the evidence of Frontinus* (Ann Arbor: University of Michigan Press, c1994); Rabun Taylor, *Public needs and private pleasures* (Rome: L'Erma Bretschneider, 2000); Gerda de Kleijn, *The water supply of ancient Rome; city area, water and population* (Amsterdam: Gieben, 2001).

literally the area where the houses ended and the *disabitato*, or the uninhabited area of orchards and vineyards began. From that point, the aqueduct channel had originally been carried westward on arches to the Baths of Agrippa, which it had been built to serve.

In 537AD, Rome's aqueducts were severely damaged or destroyed when Goth armies invaded and sacked the city. A general lack of maintenance between the sixth and late eighth centuries and rising ground levels led to the structural deterioration of the Virgo arches. Therefore, when Pope Hadrian I (772-795) restored the Virgo, his work extended only as far as the area now occupied by the Trevi Fountain while the arches closer to the Baths were not rebuilt.[4] During the later medieval period, repairs were undertaken by the *maestri di strada*, the masters of the streets, whose responsibility for the aqueducts, fountains, roads and bridges had been established during the period when the popes abandoned Rome for Avignon between 1309 and 1377.[5] Then in 1453, Pope Nicolas V (1447-1455) sponsored a restoration of the aqueduct (by then known as the Vergine), which regrettably was incomplete.[6] It was entirely possible that Nicolas and his engineers were unaware that the Salone Springs were the original aqueduct source. Rather, one or more springs closer to the city that supplemented the Salone, may have provided the entire limited supply at that time.[7]

Although incomplete, Nicolas's restoration signalled an administrative shift of papal encroachment into the newly established civil administration of public utilities – a process begun by Pope Boniface IX (1389-1404).[8] For example, in 1452, just one year before initiating restoration work on the Vergine, the Statutes of the *maestri* were revised under Nicholas's direction in a strategic move intended to curtail civic influence by placing them under papal authority.[9] Nicholas also set a precedent for subsuming infrastructure development into an

4 Four aqueducts (including the Virgo) were restored during the medieval period. See Bryan Ward-Perkins, *From classical Antiquity to the Middle Ages* (Oxford: Oxford University Press, 1984), 119-154; Robert Coates-Stephens, 'The walls and aqueducts of Rome in the early Middle Ages, A.D. 500-1000,' *Journal of Roman Studies* 88 (1998):171-76.

5 The *maestri* were responsible for the aqueduct as early as 1363, but their authority only extended as far as the city walls. See Camillo Re, *Statuti della Città di Roma* (Rome: 1880).

6 Alberto Cassio, *Corso dell'acque antiche portate sopra XIV aquidotti da lontane contrade nelle XIV regioni dentro Roma,* 2 vols., (Rome: 1756-57), I: 280. Also, see David Karmon, 'Restoring the ancient water supply system in Renaissance Rome: the Popes, the civic administration, and the Acqua Vergine,' *The waters of Rome* 3, 2005, p. 1-13, http://www.iath.virginia.edu/waters/karmon.html.

7 See Andrea Fulvio, *Antiquitates Urbis Romae* (Rome: 1527), 43v.

8 P. Becchetti, 'La Marrana dell' Acqua Mariana,' *Lunario Romano* 3 (1974): 17-19. He points out that Boniface IX reprimanded the commune for usurping power over the Acqua Marrana (an artificial stream introduced by Pope Callisto II, in 1122) where it flowed within the city walls.

9 Emilio Re, 'I maestri di strade,' *Archivio della Società Romana di Storia patria* 43 (1920): 5-102.

overall strategy to restore the prestige of the Roman Church through *renovatio Romae*, or the physical restoration of Rome itself, a process that had begun with Martin V (1417-1431) in 1420 after the return of the papacy from its second and final exile in Avignon. At that moment a new consciousness that Christian Rome was to be identified with Imperial Rome gradually emerged. Water infrastructure in particular would come to exemplify the potential for restoring Rome to its former glory by recalling the paradigm of the eleven ancient aqueducts, hundreds of fountains and numerous public baths that had once ornamented and served the ancient city.

Unfortunately, aqueducts need constant maintenance. Therefore, Pope Paul II (1464-1471) authorised another restoration in 1467, as did Sixtus IV (1471-1484) in 1475.[10] Sixtus IV's restoration was highly praised in a well-known Vatican Library mural by Melozzo da Forlì and in a largely unknown panegyric poem by Robert Flemmyng, an English traveller to Rome in 1477 in which he mentions that the water was 'almost lost'.[11] In a lengthy detailed passage, he states that Sixtus IV had a 'permanent conduit' built to the Trevi Fountain after clearing debris from the channel. The poem emphasised that the restoration was an important civic improvement. Yet, Flemmyng never mentions the Salone Springs, which indicates that the true aqueduct source was still unknown. Over the next sixty years the aqueduct was repaired at least three times: once in 1510 under Julius II (1501-1513); and twice under Leo X (1513-1521), who in 1513 decided to assign income from the *gabella del Studio* (wine tax) to pay for the work; and again in 1521, when the exposed arches that ran between the foot of the Pincian Hill and the Trevi Fountain were restored.[12]

On 6 May 1527, forty thousand mercenary soldiers of the Duke of Bourbon who had been pledged to Charles V invaded and sacked Rome, killing and injuring thousands of persons and destroying hundreds of buildings. The mercenaries occupied the city until December 1527 when they were finally forced out by the plague.[13] There was barely time to recover from the devastation of the sack before Rome was attacked once again, this time by the Tiber River, which flooded in 1530. According to eyewitness accounts, the flood,

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[10] Eugene Muntz, *Les Arts a la Cour des Papes Pendant le XV^e et le XVI^e siècle, Recueil de Documents Inédits*, Duexième Partie, Paul II 1464-1471 (Paris: 1879), p. 96-97.

[11] Robert Flemmyng, 'Meditations at Tivoli' (Rome: 1477). Translated from the Latin by G. Parks, *The English Traveler to Italy* (Rome: Edizioni di Storia e Letteratura, 1954), p. 601.

[12] For Julius II, see Francesco Albertini, '*Opusculum de mirabilibus novae et veteris urbis Romae*' (Rome: 1550), p. 3: n. 1; and for Leo X, see Raffaele Marchetti, *Sulle acque di Roma antiche e moderne*, (Rome: 1886), p. 193. For the 1521 restoration see, ASR, *Presidente delle Strade* 445: 62r-63v.

[13] Luigi Guicciardini, *The sack of Rome*, edited by James H. McGregor (New York: Italica Press, 1993).

which had the highest level recorded since antiquity at 18.95 meters above sea level, was more devastating than the sack. As with earlier floods, numerous inscriptions were placed on building façades to record its remarkable height and money was raised to clean and repair streets and buildings.[14] Then in 1535, with an unanticipated surplus in the papal treasury, Paul III (1534-1549) urged the Council to use the money to restore the Vergine. He nominated twelve 'gentlemen' to develop a strategy 'to return Acqua Vergine water to Rome, which had been lacking for many centuries.'[15] The implication that water had not flowed for 'centuries' is an overstatement, but the occasional (or perhaps frequent) lack of water at the few public fountains would have been a reality, especially during the late summer following a dry spring. Unfortunately, whatever strategy his 'experts', these 'gentlemen', were interested in pursuing was quickly laid aside once Charles V announced his plan to enter Rome in 1536. Money was needed to prepare and decorate the city for his arrival, and the still fresh memories of the 1527 sack by Charles's mercenaries turned Paul's attentions to preparing Roman defences for a potential attack.

Out of the library and into the aqueduct

Convinced that the Vergine of his day did not constitute the entirety of the ancient Virgo, Papal librarian Agostino Steuco conducted a survey of the aqueduct beginning in 1545. Steuco, a learned humanist, wrote highly praised polemical works of biblical exegesis before arriving in Rome in 1535. Once he assumed his position in the Vatican Library in 1538, his interests shifted to include archaeology, engineering, city planning and aqueducts in particular.[16] Not content with reading Frontinus's survey of the Roman aqueducts, *De Aqueductu Urbis Romae* (written in 97-98AD for Emperor Vespasian and recently rediscovered and copied by Poggio Bracciolini), Steuco set out on 'his own initiative', with Frontinus as his textual guide, to study the Virgo through first hand observation.[17] Steuco personally traced the course of its channel by finding and following the original airshafts that occurred along the route. As the aqueduct ran underground for most of its course, Steuco's efforts to become

[14] See Pietro Frosini, *Il Tevere: le inondazione di Roma* (Rome: Accademia, 1977) for an inventory of inscriptions and transcriptions of eyewitness accounts.
[15] AC, *Cred.* I, 36: 319 (27 November 1535).
[16] Ronald Delph, 'From Venetian visitor to Curial humanist: the development of Agostino Steuco's 'Counter-Reformation thought',' *Renaissance Quarterly* 47 (1994): 102-139, especially pages 106 and 129-30.
[17] Frontinus, the *Curator Aquarum* (director of water works) between 97-98 AD, gave a detailed (although sometimes inaccurate) account of the state of the water supply, the amount of water in the system, and its administration at that time. His description of the Virgo springs was accurate.

an 'expert' proved arduous. He also made detailed observations, assessed its condition along its entire length and verified that the springs at Salone were the same as those that Frontinus had described. Through his investigations he confirmed that the ancient collection basin built around the springs had deteriorated to such an extent that little of the water actually entered the channel, but rather that it flowed into one of the tributaries of the Anio River that passed nearby. In 1547, he published a treatise *De revocanda in Urbem Aqua virgine*, based on this research in which he urged Paul III to restore the Vergine.[18]

In another treatise, this one undated, Steuco proposed the construction of three public fountains one each at the beginning, middle and terminus of 'Via Pauli' (actually Via del Corso), that is at Piazza del Popolo, Piazza Colonna and Piazza Venezia.[19] The fountains were intended as ceremonial landmarks along the major processional route into the city, and as Ronald Delph points out, Steuco imagined that the fountains like the restored aqueduct 'would enhance Rome as the centre of Christianity, and renew the piety and veneration for Rome among all Christians (since in the past) such acts of benevolence and civic mindedness had awakened a sense of devotion among people as they venerated Rome as a sacred place.'[20] However, neither the restoration of the aqueduct nor the construction of new fountains occurred during Paul III's pontificate as both he and Steuco were concerned with the Council of Trent (1545-63) where Steuco died in 1548. Nonetheless, I suggest that it was his work that provided the foundation for the successful restoration of the aqueduct in 1570.

Precedence and authority

There was barely a trickle of water from the Trevi Fountain in 1548 and conditions were dire in 1550 when Julius III (1550-1555) ascended the papal throne.[21] The Roman Council issued a *decretal* on 21 July 1550 to express its concern to him about the deplorable condition of the Vergine. The Council challenged Julius to actively support the restoration work of the *maestri*, and warned that the channel was damaged and filled with debris and broken masonry in so

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[18] Agostino Steuco, *De revocanda in Urbem Aqua Virgine*, in *Opera omnia quae extant, omnie, e veteribus bibliothecis*… (Paris: 1578), 293v–96r. See Ronald Delph, '*Renovatio, Reformatio*, and Humanist ambition in Rome,' R. Delph, M. Fontaine, and J. Martin, eds., *Heresy and religion in the culture of Early Modern Italy* (Kirksville: Truman State University Press, 2006), pp. 73-92 for a discussion of Steuco's survey.

[19] Agostino Steuco, *De via Pauli et de fontibus inducendis in eam* (Rome: n.d.). In this treatise, Steuco renamed Via del Corso in Paul III's honour.

[20] Delph, 'Renovatio'.

[21] Lucio Fauno, *Delle antichtà della città di Roma* (Venice: 1548), 128r.

many places that the *maestri* were unable to carry out their work. The *decretal* stated that little water actually reached the city and that soon the supply would fail altogether. Finally, immediate action was urged in order to maintain the honour of their office as the conservators of the public realm.[22] Julius III did not respond, perhaps because he intended to use the Vergine water for his gardens at Villa Giulia, which he did the following year.[23] It also seems that Julius, like many persons, considered Tiber River water superior to that of the Vergine for drinking and therefore may have felt that to restore the aqueduct was a waste of money and resources, since Tiber water was so abundant and easily accessible.[24] In fact, *acquaeroli*, or water-sellers, collected water from the River, which they decanted for a week and then sold from barrels carried from door-to-door on donkeys.[25]

Ten years later, the slowly moving wheels of papal administrative machinery began to turn again. In the meantime, Rome had been ravaged by another flood in 1557. This flood was nearly as catastrophic as that of 1530 and it caused great hardship to the city since the most important commercial bridge, the Ponte Santa Maria that connected Trastevere to the left bank of the city was destroyed. This flood was still fresh in the minds of civic and the papal officials when finally, in 1560, after a year of serious water shortages both papal and civic assemblies resumed discussions to restore the Acqua Vergine.[26] The first discussion was held at a public meeting of the Roman Council on 4 October 1560, when Pius IV appointed a papal commission to oversee a project to tap the ancient springs, to restore and clean the entire aqueduct and to bring that water into Rome 'for the benefit and beauty' of the city. At the same time, two cardinals were directed to meet with the civil magistrates to hear their opinions, which apparently went unheeded.[27]

The contract to supervise the work was contested between Pirro Ligorio, an antiquarian and architect who designed the spectacular waterworks at Villa

[22] AC, *Cred.* 1, 36: 695, (21 July 1550).

[23] David Coffin, *Gardens and gardening in Papal Rome* (Princeton: Princeton University Press, 1991), 80-83.

[24] For example, see Alessandro Traiano Petronio, *Ad Julium III Pont. Opt. Max. de Aqua Tiberina. Opus quidem novum sed ut omnibus qui hac aqua utuntur utile, ita et necessariusm* (Rome: 1552), with passages cited in Cesare D'Onofrio, *Le Fontane di Roma* (Rome: Roma Società, 1986), 38-9.

[25] Rodolfo Lanciani, *The golden days of the Renaissance in Rome* (Boston and New York: Houghton Mifflin and Company, 1906), 80.

[26] For water shortages, see Rodolfo Lanciani, *Le acque e gli Acquedotti di Roma antica* (Rome, 1881), 341

[27] AC, *Cred.* 1, 21: 48v, (4 Oct. 1560). For Pius IV's urban projects and the roles of both Trevisi and Ligorio, see Pamela Long, 'Engineering, power, and knowledge in early Counter-Reformation Rome, c. 1557-1570,' an unpublished paper circulated by the Davis Center, Princeton University, December 2004.

d'Este in Tivoli, and Antonio Trevisi, a military architect from Lecce, who was awarded the contract by the Camera Apostolica in a secret meeting on 18 April 1561 and named *Architetto di Nostro Signore*, Architect to the Pope. Trevisi, who moved to Rome in 1558, had already completed two projects in the city including the important publication of a second edition of the 1551 Bufalini Plan of Rome (an early orthogonal city plan) and a treatise on the inundations of the Tiber River, both in 1560. These works reveal his broad knowledge of the city and must have provided sufficient 'expertise' to recommend him for the work.[28] Ligorio, however, had actually designed fountains and distribution conduits for the Villa d'Este, and he was either currently engaged in, or had recently completed, his own investigation of the Vergine. He had even made on-site analytical drawings of the different phases of restoration on the aqueduct channel where it was carried above ground on arches outside the city walls.[29]

Apparently, the choice of Trevisi was not announced to the Roman Council until two months later, when the papal committee supplied them with details about his fee and how the costs were to be divided between the various constituencies: 5000 *scudi* from the pope; 5,000 from the College of Cardinals; 3,000 from the Cancelleria and the remaining 7,000 from the Roman Council (through taxes on the people of Rome), for a total of 20,000 *scudi*.[30] With this *fait accompli*, the Camera Apostolica effectively wrested control from the Roman Council. As David Karmon emphasises, despite the benefit of their accumulated knowledge and experience with supervising the maintenance of the Acqua Vergine for over 200 years they were marginalised once again.[31] In order to protect their interests the Council felt it necessary to appoint its own oversight architect, Bartolomeo Gritti, which it did in a secret meeting held on 19 February 1562. Gritti was mandated to report to four Council appointed deputies – Mario Frangipane, Rutilio Alberini, Horatio Nari and Luca Peto.[32] Perhaps in retaliation, the Council was slow to

[28] Trevisi was later described as a schemer and a developer of 'mysterious systems and secret methods'. But, see G. Beltrami, *Leonardo Bufalini e la sua pianta topographica di Roma* (Florence: 1880), 31-32, and 371-74, and Long, 'Engineering,' p. 23, who provides a corrected citation for the original document; ASR, *Camerale* 1, *Registro* 1520 (1560-1565).

[29] Pirro Ligorio, *Libro XVI dell'antichita di Pyrrho Ligorio Patritio Neapolitano et cittadino Romano, nel quale si tratta delli luoghi, et città, vichi, castelli, et ville, et monti, et d'altre cose illustri*. I would like to thank David Karmon who directed me to the Vatican copy of this original undated manuscript (made for Queen Christina of Sweden) that is housed in the Biblioteca Nazionale di Napoli. BAV, *Ottob. Lat.* 3373, 13v. The drawings are published in Karmon, 'Restoring,' figures 9 & 10.

[30] AC, *Cred.* I, 21: 86r-87v, (3 June 1561).

[31] Karmon, 'Restoring,' p. 10.

[32] AC, *Cred.* 1, 21: 147v-148v, (19 February 1562). Gritti was also known as Bartolomeo Gripetto.

remit its portion of the restoration costs, as it was pressed by the Camera Apostolica on at least five separate occasions between April 1562 and January 1563 to pay their share.[33]

The first payments were divided between Trevisi and the '*minori concessionari delle opere*', or sub-contractors, whom he had engaged for the actual work. Trevisi's title was *appaltatore*, which can mean either tax collector or contractor, and he probably held both positions, overseeing the collection of the taxes to pay for the construction and also supervising, and paying for, the work itself.[34] Regardless of his role, he seems to have found himself quickly at odds with the masons, surveyors and other persons responsible for carrying out the work. It appears that the situation was so acrimonious that Cardinals Serbelloni and Lomellino (who had charge of the papal committee) made it clear to Pius IV that the sub-contractors insisted that Trevisi was impossible to work with and they urged Pius to terminate Trevisi's contract.[35] Yet, for reasons that are still unclear, Trevisi was not fired. According to Ligorio, Trevisi died while in jail, presumably on charges related to the Acqua Vergine restoration.[36] Apparently work stalled altogether since the restoration was not mentioned again in Council minutes until November 1564 when it was reported that several council members (including Luca Peto) discussed the subject with the pope.[37]

After Pius IV's death in 1565, the work force was reorganised by his successor Pius V who ordered a full accounting of the work.[38] Peto, a noted jurist and civil magistrate who would later be instrumental in formulating a new law code under Pope Gregory XIII (1572-85), assumed a far more important role. The Council entrusted him to examine the springs and the entire aqueduct. According to Peto's report on the restoration, which he published five years later, he determined that little work had actually been accomplished in spite of

33 AC, *Cred.* 1, 21: 163r-163v, (1 April 1562); 169r, (5 May 1562); 189v-190r, (12 July 1562); 193r, (14 July 1562); and 211r, (18 January 1563). For the Roman Council's financial responsibility, see AC, *Cred.* 1, 21: 116-17 (10 Sept. 1561); 119v (16 Oct. 1561); and 125v (13 Oct 1561). For the Council's unwillingness to pay, see AC, *Cred.* 1, 21: 169 (5 May 1562); 183v (17 July 1562); 189v-190 (4 July 1562); 193-194 (14 July 1562); 206 (17 Dec. 1562); 211 (18 Jan 1563); and 226v (4 March 1563).

34 Trevisi purchased a contract to collect taxes for the restoration of the Ponte Quattro Capi. See ASR, *Taxae Viarum*, 445: 385r-397v, (30 July 1560). I would like to thank Pamela Long for drawing my attention to Trevisi's name on this document.

35 ASR, *Cit. Reg. Divers. Pii IV* 1563-65: 226, cited in Beltrami, 'Bufalini,' p. 40.

36 Ligorio, '*Libro XVI…*,' folio 13v. Karmon, 'Restoring,' p. 11-12, discusses Ligorio's unique grasp of earlier restoration techniques employed on the Acqua Vergine.

37 AC, *Cred.* I, 37: 186v, (1 November 1564).

38 AC, *Cred.* 1, 23: 4v, (15 June 1566).

39 I would like to thank Leonardo Davide for translating selected passages of the 1570 edition, and Pamela Long who allowed me to use her translation of the 1573 edition of Peto's treatise.

the fact that nearly all the money was gone.[39] In his report Peto carefully cited the authority of both Pliny and Frontinus and compared what he saw to what they had seen, yet, he failed to refer to the fastidious examinations of Steuco or Ligorio.[40] Whether he knew of their work remains unknown, but it seems unlikely that he was ignorant of Ligorio's nearly contemporary survey work, although he may not have read Steuco's treatise.

In his efforts to increase papal control at the expense of the Council, Pius V established the *Congregatione cardinalizia super viis pontibus et fontibus* (Committee of cardinals in charge of roads, bridges and fountains) in 1567.[41] He created the *Congregatione* (which I shall refer to as the Committee) specifically to oversee and facilitate the restoration of the aqueduct. Like other papal committees on which cardinals served at the pleasure of the pope, and which dealt with the physical fabric of the city, it overlapped with existing civic committees.[42] The imbrication of the rival cardinalate committee over the *maestri* who already held responsibility for Rome's roads, bridges and fountains was clearly intended to erode civil authority. Three cardinals, two other papal officials and two noble representatives were named as permanent members of the Committee. Six positions were assigned to rotating officers of the Roman Council, thus further undermining their role.[43]

It was another year before a contract with the stonemasons and trench diggers was signed in September 1568, the same month that Pius V appointed Giacomo Della Porta (1532-1602) as the architectural advisor to the Committee.[44] Highly respected, Della Porta already held the office of *Architetto del Popolo Romano*, Architect of Rome, to which the Council appointed him after his predecessor Michelangelo died in 1564. After the Trevisi scandal, Della Porta's appointment to the Committee was specifically recommended because of his reputation for diligence and honesty.[45] Perhaps the most persuasive argument for choosing Della Porta for this important project was the fact that he had worked on the Basilica of St. Peter's and that he had respected the design precedents set by Michelangelo for its completion. Chosen because he understood the value of authority, including that of Michelangelo, Della

40 Luca Peto, *De restitutione ductus aquae Virginis* (Rome, 1570). The Council revised the Statutes and Gregory XIII approved them in 1580.

41 ASR, *Libri Congregatione* 1: 12, (17 Sept 1567); BAV, *Urb. Lat.* 1040: 562v; AC, *Cred.* I, 1: 96.

42 See Nussdorfer, 'Civic politics,' p. 45, who describes the 'cumulative…construction' of urban administration as the Camera Apostolica appointed new officials to regulate offices that were already administered by civic officials.

43 Pio Pecchiai, *Acquedotti e Fontane di Roma nel Cinquecento* (Rome: Staderini, 1944), 15.

44 ASR, *Congregatione*, I: 16v, (3 November 1568).

45 For Giacomo Della Porta's life, see *Dizionario Biografico degli Italiani,* Alberto M. Ghisalberti, ed., vol. 37 (Rome: Istituto della Enciclopedia italiana, 1989), 160-70.

Porta would in fact be called upon to devise new strategies to see the Vergine restoration through to completion. As work progressed, his responsibilities increased and he took on jobs that had previously been awarded to others. Ultimately he oversaw the repair of the entire length of the channel, the complete overhaul and amplification of the original springs, the restoration of the holding basin at the springs, the survey for the distribution routes within the city, the design and construction of a series of new public fountains and the design and arrangement of the conduits to deliver the water to them.[46]

Finally on 30 August 1570 'amid great public rejoicing', water poured again from the Trevi Fountain, which terminated the restored aqueduct.[47] Up to this point, the model of ancient Rome had been ever present to Pius V, his committee of cardinals, the architects, engineers and construction crews. Vestiges of ancient Roman water engineering projects, including fragments of aqueduct arches and Imperial baths, could still be seen within the city walls and the Vergine itself had been thoroughly studied by Steuco and measured by Ligorio. In fact, the entire process of restoring the aqueduct was largely imitative of ancient precedents. Not only was most of the original conduit restored, but also gravity flow technology and the construction techniques employed, were essentially the same in the late sixteenth century as they had been in antiquity. The same cannot be said for the next task – distributing the water.

Observation and experiment

An astounding quantity of water (nearly 1200 litres per second), had to be delivered through gravity to new public and private fountains. To do this entailed making decisions about how much water should be reserved for public fountains, where those fountains should be placed, how much money was needed to construct them, who should pay for them and how much water should flow to each one, as well as how water was to be delivered to private subscribers and how much that water would cost. Unfortunately, direct familiarity with this particular type of large-scale engineering project – its planning, construction and administration – was limited in late-sixteenth century Rome.[48] Thus, from this point forward nearly every step in the process would require

46 Bartolomeo Gritti was second in command to Giacomo Della Porta at this time, and would have supervised much of the construction work.

47 Carlo Fea, *Storia delle acque antiche sorgenti in Roma* (Rome: 1832), 65.

48 There was one high-pressure line within Rome, the Acqua Damasiana, a two-kilometre long underground channel that brought water from a nearby spring to several fountains in the Vatican. Because there was more than twenty-five metres of available pressure in this system and because it was confined to a restricted area with clear site lines, it was not an appropriate model for the Vergine.

innovative approaches – from surveying the routes, designing civic fountains, laying the conduits to them and building the drains that would carry away any excess water. What was needed was a clear understanding of how to move water that was under very low pressure to a series of new fountains located across a two-square kilometre distribution area in the Campo Marzio. There was less than two meters of available pressure in some areas and never more than five meters under the best circumstances. For these reasons, it is particularly interesting to speculate why Pius V did not hire one of the many highly respected hydraulic architects working elsewhere in Italy at the time, rather than the local 'experts'. Perhaps this was seen as a way to monitor the process more carefully.[49]

Just as Nicholas V had used the Vergine restoration to extend papal hegemony over the *maestri* and to erode the autonomy of the Council, Pius V and the members of the Committee used the same strategy to establish even greater control over the distribution of Vergine waters. Having never administered such a complex water project, the Committee and the Council disagreed over questions of jurisdiction, nowhere more ardently than over the contract to construct and lay the distribution conduits under Roman streets. Rather than allow the Roman Council to supervise the work, the contract was the focus of a protracted power play that led to costly mistakes and lengthy delays. Naturally, Pius V and the Committee wanted to maintain all the power in their own hands, yet the Council was unwilling to resign itself to a role as mere executor of their decisions. Specifically, the *maestri*, who had actual jurisdiction over the streets and piazzas where the conduits were to be laid and the fountains built, wanted a more decisive role. Having the power to choose the 'expert' who would design and oversee the work was not only a question of prestige; the Council was adamant that its responsibility came from the authority of the people, to whom, according to the Statutes, it was the guardian of the people's interest.[50]

In spite of repeated appeals from the Roman Council, the Papal Committee hoped to exclude the municipal authorities from the water distribution process altogether. On 16 May 1571, as both an expedient and in order to thwart the Council, the Committee (in an act that was reminiscent of the surreptitious contract ten years earlier with Trevisi) concluded an agreement with a sculptor, Guglielmo Della Porta (1515-1577; no relation to Giacomo), to construct and lay stone distribution conduits.[51] This choice was problematic and had immediate negative consequences, as he had never designed a civic

49 See Coffin, 'Gardens,' p. 50-53, for the relevant experience of hydraulic architects.

50 AC, *Cred.* I, 25: 13, (16 January 1561).

51 ASR, *Notaio Gracchi*, 39: 183v, (16 May 1571); translated in part, in D'Onofrio, 'Fontane,' p. 65.

fountain, let alone the conduits to deliver water to it. An interest in hydraulics is nonetheless suggested by the fact that he owned a treatise by Leonardo da Vinci (the Leicester Codex), which is concerned in part with water.[52] Although the Council opposed the choice of Guglielmo, he was trusted and admired by many powerful individuals, as Cardinal Alessandro Farnese, Paul III and Paul IV had all commissioned sculptures from him in the past.

According to the contract, two sets of conduits were to be completed in two years. They were to be laid beneath the public streets from a new underground *castello* (distribution chamber) in the northern part of the city that would supplement the original terminal *castello* at the Trevi Fountain.[53] Designed by Giacomo Della Porta, the new distribution tank was built about six meters below ground level at San Sebastianello, at the foot of the Pincian Hill just north of the area now known as Piazza di Spagna. Its underground location was dictated by the operational level of the water in the aqueduct – only about 19.70 meters above sea level, which was about seventy centimetres higher than at the Trevi Fountain. By June 1571, the Committee proposed to distribute water from the new *castello* to the major piazzas and streets of the Campo Marzio. In his capacity as architectural advisor to the Committee, Giacomo Della Porta recommended that construction begin immediately on nine of them, with single fountains in Piazza del Popolo, Piazza Colonna, Piazza della Rotonda, Piazza San Marco, Campo dei Fiori, Piazza Giudea and Piazza Montanara; and two fountains in Piazza Navona.[54] (Ill. 12)

Although surveying techniques were widely employed at this time for building construction and for laying out streets, there was no survey of the entire city, nor were there surveys of individual neighbourhoods. More importantly, contour elevation mapping had not yet been developed. Della Porta needed to establish the level of available pressure in each proposed site. Therefore, he had to be able to form some kind of mental or graphic image of the topographic relationship between the individual fountain sites and San Sebastianello.[55] To do this, he needed to establish a datum against which he could measure

[52] Carlo Pedretti, *Leonardo Da Vinci: the Codex Hammer, formerly the Codex Leicester*, Catalogue by J. Roberts, (London: Royal Academy of Arts, 1981), item 2. I would like to thank Joyce Pellerano Ludmer of the Getty Research Institute for her help in locating this reference.

[53] AC, *Carte Boccapaduli*, II, 4: 64; also cited in Pecchiai 'Acquedotti,' p. 28.

[54] The Committee made an earlier proposal in 1570. AC, *Cred.* VI, 50: 4, (7 July 1571), published in D'Onofrio 'Fontane,' 90, who dates the plan November 1570. Pecchiai, 'Acquedotti,' p. 28, dates it later than 6 June 1571 when a proposal to lay distribution pipes to Piazza del Popolo was first mentioned.

[55] Although scant proof of his survey survives, there is one incomplete drawing in Giacomo Della Porta's hand of the proposed route between San Sebastianello and Piazza Navona that confirms that

the level of the water at the *castello* that could then be applied throughout the distribution area.

How could Della Porta understand the larger landscape of water distribution without conducting a survey of the entire Campo Marzio? We do not know how he worked, but I suggest that he would have naturally used his own understanding of the city around him – an understanding that came from direct observation. It does not seem unreasonable to propose that he could have intuitively understood that the many inscriptions, mentioned earlier, that recorded the historic Tiber floods could provide the necessary datum from which his own survey of the Campo Marzio could begin. These commemorative inscriptions marked the highest level reached by each flood and permanently inscribed the memory of a temporary high-water mark (literally a contour line) that had left its stain on building walls throughout the Campo Marzio. Although this temporary high-water mark was not in fact horizontal (sloping slightly toward the south-west as the river approached its mouth) nonetheless, it was perceived as level, since the residual contour line that was left, just as the water began to recede, was essentially horizontal within each of the piazzas where floodwaters had stood.[56]

There were at least ten markers for the 1495 flood, ten for the 1530 flood and three for the 1557 flood, and nearly all of them were situated within the Vergine distribution area, including one from 1530 located in Piazza del Popolo where the first civic fountain was to be built. (Ill. 12) By shifting his viewpoint to think of a continuous flood line as his datum, it would have been a simple surveying task for Della Porta to gauge the difference in elevation between this inscription and the *castello* at San Sebastianello or the level at which water arrived at the Trevi Fountain. In fact, the level of water in the *castello* exceeded the flood line by 75 centimetres, a difference that could be extrapolated for use in the specific locations chosen for fountain sites. Only after these elevations had been established could Giacomo Della Porta design the individual fountains – each reflecting in its height its unique relationship to the *castello* – with taller fountains designed for the lowest elevations, and shorter fountains for the higher elevations.[57] (Ill. 13)

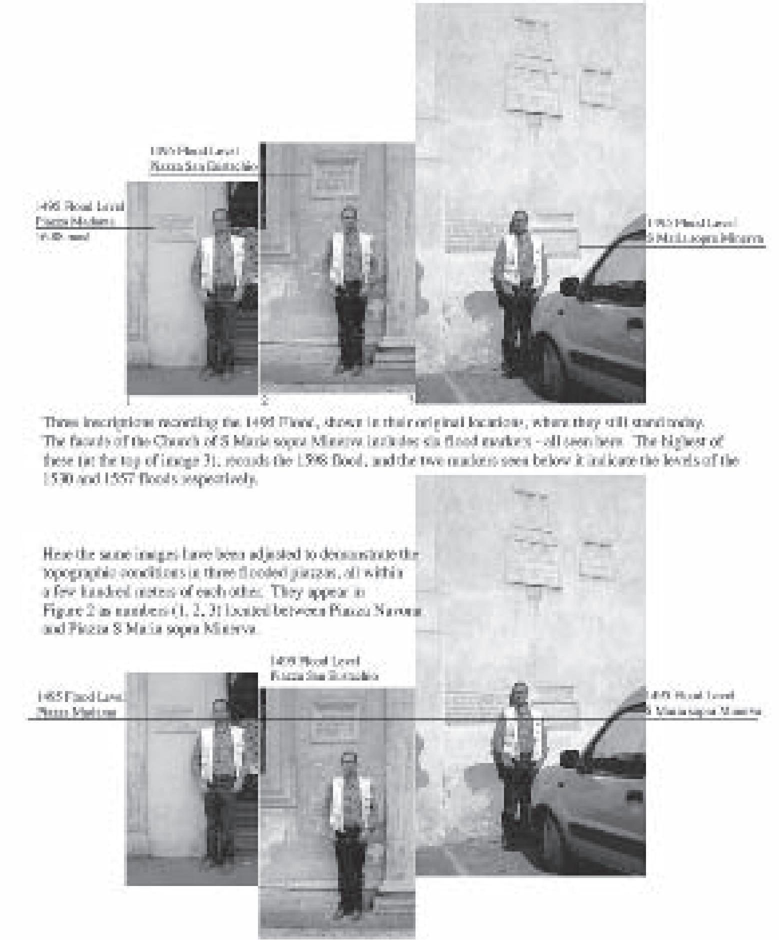
he tackled this problem at the beginning of the design process. BAV, *Vat. Lat.* 11257, c. 149. It is generally assumed that ancient Roman surveying techniques were still in use in the late sixteenth century and the aqueduct surveying team probably employed a type of plane table, known as a *chorobates*.

56 Photographs taken after the 1966 Florence flood clearly demonstrate this point.

57 For the design of these fountains, see Katherine Rinne, 'Fluid precision: the Acqua Vergine fountains of Giacomo Della Porta,' *Landscapes of memory and experience*, Jan Birksted, ed., (London: Routledge, 2000).

Ill. 12. A map showing the proposed Acqua Vergine fountain sites (shown as dots) in relation to today's street plan. The stars represent some of the thirty-three documented commemorative inscriptions for the 1495, 1530, and 1557 floods that could be seen in 1570. Multiple inscriptions could be seen at several of these locations. © Katherine Rinne, 2006.

Unfortunately, it quickly became clear that there were other unanticipated problems that needed to be solved. In June 1571, Guglielmo Della Porta began construction of the first conduit, which was built from San Sebastianello to Via Paolina and then north to Piazza del Popolo. He used a type of travertine known as *pietra de la cava d'Orta* that he described as being 'similar to marble'.



Ill. 13. Composite images showing how flood markers provide a topographic datum that can be used to determine relative elevations in the Campo Marzio. In the top image, the street level serves as a datum. When the viewer perceives the flood level as the datum, changes in elevation can easily be observed, calculated, and mapped. (Composite, © Katherine Rinne, 2006; photography provided courtesy of Rosella Nastri and Bruno Leoni).

The stone conduits were to be made in three sizes of six, eight or twelve *palmi* in length (approximately 1.34, 1.78 or 2.68 meters) with a one and one-half *palmi* (33 centimetres) diameter centre bore to carry the water. The cost was set at thirteen *scudi* per *canna* (10 *palmi* = 1 *canna*) and included constructing the necessary vents, purgation chambers, junction boxes, iron bars, lead, mortar and stucco.[58] Unfortunately, technical problems soon developed, as the choice of stone was entirely wrong for water conduits. After only one hundred meters of the conduit had been laid, the first test occurred in October 1571. Ordinarily, a test was conducted to determine whether the course had been properly surveyed to insure a constant gradient for the conduit. In this case, the survey was correct but the material failed to perform as planned. According to the reports made at the time, the stone conduits leaked 'like a sieve' allowing copious amounts of water to fill the deep trenches and to even flow out into the streets. The conduit was seriously flawed and could not be repaired. Work ceased immediately and Guglielmo was fired.

The Committee's inability to supervise the construction work was a great impediment, but as Pio Pecchiai points out, Pius V must also be held culpable for granting them too much power and for approving the entirely unsuitable choice of Guglielmo.[59] Had the *maestri* themselves, with their extensive experience of overseeing urban restoration and construction projects, been given greater authority to choose an experienced hydraulic architect and to supervise the work, problems associated with inappropriate materials might have been avoided.

A different sort of problem occurred in Piazza del Popolo where the first public fountain, designed by Giacomo Della Porta, was inaugurated in 1575. In late 1577, it was necessary to provide the upper chalice of the fountain with a new pedestal, which was substituted 'in order to lower the fountain.'[60] This was necessary because the pressure was too low to achieve an impressive jet of water at the top of the fountain. Yet, Giacomo, unlike Guglielmo, was not fired because this minor mistake could be easily rectified.

Why was this modification necessary? Several explanations are possible, including the fact that seasonal variations in the water supply could reduce available pressure, but I shall focus on only one.[61] In 1575, this was the only fountain receiving water from the *castello* at San Sebastianello, but between then and 1577 when the alteration was deemed necessary, three additional public fountains and nearly thirty private subscribers drew water from the same *castello*. As distribution conduits were installed for each of these new fountains, the level of available pressure in the *castello* was altered and it appears that it

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58 Pecchiai, 'Acquedotti,' p. 23-5, who cites from ASR, *Notai Gracchi*, 1571: 183ff.

59 Pecchiai, 'Acquedotti,' p. 22-27.

60 Pecchiai, 'Acquedotti,' p. 79, includes pertinent documents from the Registri dei '*Mandati a favore degli Offiziali et artisti del Popolo Romano,*' AC, *Cred.* VI, 23: 136, (21 September 1577); 138, (25 & 26 October 1577); and 140, (13 & 20 January 1578).

61 See Rinne, 'Fluid precision' for a discussion of conditions affecting the flow of water to the fountain.

was not until 1583 that a plan had evolved to insure that all fountains drew water at the same level in order to equalise pressure across the network.[62]

Once contingencies such as these became more clearly understood by the 'experts', the entire process of surveying routes, laying conduits, designing fountains and apportioning and delivering water to them, flowed almost effortlessly. By 1585, when construction began on the second aqueduct – the Acqua Felice – there were several kilometres of conduits that delivered Vergine water to six opulent public fountains, new public drinking fountains, animal troughs, at least one public laundry and over fifty private palaces. Within the few years of Pius V's papacy, a distribution plan was in place and it prevailed more or less intact for the next three hundred years. Furthermore, there was now an emerging group of local 'experts' (most of whom were architects) versed in designing and building hydraulic projects.

Conclusions

The restoration of the Acqua Vergine and the distribution of its waters to public and private fountains at the end of the sixteenth century was a major engineering feat – one that was the focus of a protracted struggle between the papal administration and the Roman Council to control the construction process. While various popes used the administration of the aqueduct restoration to wrest privileges away from the Council and as a means to restore its temporal power, the Council sought to uphold its newly won authority to maintain the public realm by asserting its prerogative to choose contractors and supervise construction. In the end, the Council ceded much of its traditional authority.

The work was characterised by two distinct phases – the aqueduct restoration, and the distribution of its water – both carried out by 'experts' who approached their work with widely varying types of 'expertise'. During the first phase, the authority of architectural and engineering precedents was respected and traditional materials and construction techniques were used to restore the aqueduct. During the second phase, direct observation of natural phenomena and of Rome itself, provided new insights that facilitated the distribution of the water. Direct observation led the 'experts' charged with carrying out the work, to experiment (sometimes unsuccessfully) with surveying, and with fountain and conduit design. These experiments led to some failures, but also to innovative insights. Within a few short years, the 'expertise' of the many 'experts' had expanded to include hydraulic engineering.

[62] BAV, *Codice Chigiano*, H II 43: 9r, (9 December 1583).

Although the Vergine would be continually enlarged with new springs, conduits and fountains, this first iteration provided the technical and administrative framework upon which the Acqua Felice and the Acqua Paola were later grafted to create a single, integrated, water distribution system, composed of the three individual networks that together served the entire city for the next three hundred years. The restoration of the Acqua Vergine marked the beginnings of the Rome's real urban 'renaissance'. By following precedents and tackling on-site experimentation, this restoration was instrumental in achieving the longed for *renovatio Romae*, the physical transformation of the city that was considered crucial for its spiritual renaissance as the centre of the Christian world.

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Primary sources

Abbreviations: Archivio Capitolino di Roma (AC); Archivio di Stato di Roma (ASR); and Biblioteca Apostolica Vaticana (BAV).

AC, *Cred.* I, 1: 96.

AC, *Cred.* 1, 21: 48v, 86r – 87v, 116-17, 119v, 125v, 147v-148v, 163r-163v, 169r, 183v, 189v-190r, 193r-194v, 206r-v, 211r, and 226v.

AC, *Cred.* 1, 25: 13.

AC, *Cred.* 1, 23: 4v

AC, *Cred.* I, 36: 319; 695.

AC, *Cred.* I, 37: 186v.

AC, *Cred.* VI, 23: 136, 138, and 140, 13.

AC, *Cred.* VI, 50: 4; 59: 3.

AC, *Carte Boccapaduli*, II, 4.

ASR, Camerale 1, Registro 1520 (1560-1565).

ASR, *Cit. Reg. Divers. Pii IV* 1563-65.

ASR, *Libri Congregatione* 1

ASR, *Notaio Acque e Strade O. Gracchi*, 39 and 1571.

ASR, *Presidente delle Strade* 445.

ASR, *Reg. mandatorum Pii V incepti a mense aprilis 1566 usque ad annum 1573*.

Albertini, Francesco, '*Opusculum de mirabilibus novae et veteris urbis Romae*' (Rome, 1550).
BAV, *Codice Chigiano*, H II 43: 9r, 9 December 1583.
BAV, Ottob. Lat. 3373.
BAV, *Urb. Lat.* 1040: 562v.
Fabretti, Rafaello. *De Aquis et Aquaeductibus Veteris Romae* (Rome: 1680).
Fauno, Lucio, *Delle antichtà della città di Roma* (Venice: 1548).
Flemmyng, Robert, 'Meditations at Tivoli' (Rome: 1477). Translated from the Latin by G. Parks, *The English Traveller to Italy* (Rome: Edizioni di Storia e Letteratura, 1954).
Frontinus, Sextus Iulius, *De Aqueductu Urbis Romae*, edited with introduction and commentary by Robert H. Rodgers (Cambridge and New York: Cambridge University Press, 2004).
Fulvio, Andrea, *Antiquitates Urbis Romae* (Rome: 1527).
Guicciardini, Luigi, *The Sack of Rome*, edited by James H. McGregor (New York: Italica Press, 1993).
Peto, Luca, *De restitutione ductus aquae Virginis* (Rome: 1570).
Petronio, Alessandro Traiano, *Ad Julium III Pont. Opt. Max. de Aqua Tiberina. Opus quidem novum sed ut omnibus qui hac aqua utuntur utile, ita et necessariusm* (Rome: 1552).
Re, Emilio, 'I maestri di strade,' *Archivio della Società Romana di Storia patria*, 1920, 43.
Re, Camillo, *Statuti della Città di Roma* (Rome: 1880).
Steuco, Agostino, *De revocanda in Urbem Aqua Virgine*, in *Opera omnia quae extant, omnie, e veteribus bibliothecis* (Paris: 1578), 293v-96r.
Steuco, Agostino, *De via Pauli et de fontibus inducendis in eam* (Rome: n.d.).

Detail from Jonas Moore, *A Mapp of* y^e *Great Levell of* y^e *Fenns*…. The entire map measures 1950 × 1400 mm., and was printed as a series of sixteen plates, of which this is plate #7. Photo used by permission of the British Library, shelfmark Maps 184.L.1.

Amending nature: draining the English Fens

Eric H. Ash

The draining of the English Fens was one of the most ambitious technical undertakings of the seventeenth century. While previous efforts to drain tiny portions of the Fens date back to ancient times, by 1600 investors and land speculators were seeking to drain ever greater regions all at once; the largest single drainage project took place in an area known as the Great Level (later called the Bedford Level, after the project's largest investor, the Earl of Bedford). The Great Level drainage was hugely expensive, costing hundreds of thousands of pounds, and took more than two decades to complete – work began in earnest in 1631, during the reign of King Charles I, but was not adjudged to be completed until 1652, after Oliver Cromwell and the Parliamentary army had defeated the royalists and executed the king.[1] The investors' goal in draining such a vast expanse of wetland was to 'improve' it: to increase its value and productivity as arable land by making it dry enough to grow grain and other crops. The owners and investors would thus realise a profit from the land's enhanced rent or resale value, as well as from its ability to produce agricultural commodities that could be sold in Britain's burgeoning market-oriented economy.[2] Their efforts eventually resulted in the creation of some of England's richest farmland.

[1] For a narrative history of the drainage of the Fens, the two best sources are still H. C. Darby, *The draining of the Fens* (Cambridge: Cambridge University Press, 1956), and Dorothy Summers, *The Great Level: a history of drainage and land reclamation in the Fens* (Newton Abbot and London: David & Charles, 1976). See also Frances Willmoth, *Sir Jonas Moore: practical mathematics and Restoration science* (Woodbridge, Suffolk: The Boydell Press, 1993), chap. 3; and Samuel Wells, *The history of the drainage of the Great Level of the Fens, called Bedford Level; with the constitution and laws of the Bedford Level Corporation*, 2 vols. (London: R. Pheney, 1828-1830).

[2] On the seventeenth-century English 'improver' movement and its connection to the rise of a market economy, see Joan Thirsk, *Economic policy and projects: the development of a consumer society in Early Modern England* (Oxford: Clarendon Press, 1978); idem, gen. ed., *The agrarian history of England and Wales*, 8 vols., Vol. V, pt. II: *1640-1750, agrarian change* (Cambridge: Cambridge University Press, 1985), chaps. 14, 16-17; idem, *English peasant farming: the agrarian history of Lincolnshire from Tudor to recent times* (London: Routledge & Kegan Paul, 1957); Christopher Hill, *Reformation to Industrial Revolution: a social and economic history of Britain 1530-1780* (London: Weidenfeld & Nicolson, 1967).

Yet the Great Level drainage, together with the other fenland drainage projects, was also highly controversial, from the moment of its inception until well after the work was completed. It generated enormous upheaval for those who lived and worked in the Level, for whom the drainage works represented yet another instance of expanding royal tyranny and crass royal favouritism toward the moneyed interests of London, at a time when similar complaints from across the realm helped to provoke the English Civil War. As their lands were drained, not only did the fenland inhabitants lose their traditional economies and ways of life, they were also deprived of a large percentage of their commons, which were awarded to the drainage investors outright to compensate them for their efforts. With thousands of acres of once-common lands being enclosed, sold, and resold as newly private estates, the drainage thus sparked one of the greatest land speculations since the dissolution of the monastic landholdings in the mid-sixteenth century. Predictably, the fenlanders' frustration and resentment at such high-handed treatment were often expressed through violence – riots were quite common in recently drained areas, with the drainage works themselves often serving as principal targets for destruction, and fenland areas were among the most restless in England throughout the Civil War and Interregnum.[3]

Beyond the political and social unrest caused by the Great Level drainage, however, the project also exposed some deep disagreements among seventeenth-century Englishmen concerning the natural world and mankind's proper role within it; these debates are the focus of the present essay. Not everyone, for instance, thought it necessary to drain the Great Level in order to make the land fruitful and its people prosperous. While proponents of the drainage depicted the Level as a perennially flooded wasteland, and its inhabitants as a poor, backward and sickly people, fenland natives argued that their lands were actually quite productive in ways other than cereal agriculture, due in large part to their predictable tendency to flood.[4] Even among the prospective drainers themselves, moreover, there were several competing ideas as to how such a vast and complex undertaking might best be achieved, with little consensus as to precisely how much and what kind of human intervention would be required to effect an optimal outcome.

Many of the controversies surrounding the Great Level drainage were rooted, at least in part, in divergent conceptions of the natural environment.

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[3] Keith Lindley, *Fenland riots and the English Revolution* (London: Heinemann Educational Books, 1982); see also Darby, *Draining*, chap. 2; W. B. Stonehouse, *The history and topography of the Isle of Axholme: being that part of Lincolnshire which is west of Trent* (London: Longman, Rees, Orme, & Co. 1839), pp. 71-117.

[4] Joan Thirsk, *Peasant farming*, chap. 1.

The investors, inhabitants, engineers, surveyors and others involved at various levels of the project did not all perceive their watery world in the same way, and they disagreed about its fundamental nature. What exactly were 'the Fens', and what ought they to be? What was the appropriate role for men, in bridging the gap between the two? Could a better fenland somehow be forged from the existing one, and if so, how? Did nature simply require a slight nudge in the right direction, in order to assist its more beneficent tendencies? Or was nature somehow sick or broken, and in need of a major re-conception before it might be made to function properly? Were the Fens something to be helped along, or something to be struggled against?

Seventeenth-century English attitudes toward the flooded Fens, and toward nature in general, were complex and often in opposition to one another. Some saw in the Fens a peculiar instance of divine creation, which God had intended should be flooded for a reason. The Fens thus represented an organic, teleological entity, operating according to its own established rules (in accordance with Aristotelian natural philosophy), rather than the mere convenience of its human owners and inhabitants. Although not so valuable for conventional cereal agriculture, if accepted on their own terms the Fens might still yield a rich abundance of commodities (such as grass, fish, and fowl), ripe for use and exploitation. Others, however, saw within the Fens the seeds of something greater. From this perspective, the Fens were a reactive, almost mechanical system that might be rationalised and transformed into productive farmland through careful observation, artificial modification, and diligent maintenance. Indeed, nature itself supplied the very model for the Fens' renewal, in the better-draining 'uplands' that surrounded the region. Nature thus provided both a laboratory in which a more rational artificial landscape might be constructed, as well as the inspiration for that new landscape. Both pro- and anti-drainage partisans viewed the Fens as a valuable part of the economy of a prosperous and mighty English commonwealth, and they did not hesitate to deploy the idea of 'nature' rhetorically to support their respective positions. Yet their diverse portrayals and uses of 'nature' reveal a growing divergence in their perceptions of the natural environment, particularly with respect to the degree of human action required to cultivate, improve, and profit from it.

This essay will examine two debates central to the drainage effort in the Great Level of the Fens: whether or not the Level ought to be drained in the first place, and how best to accomplish the drainage. Both of these disputes were very public, with each side producing a number of printed texts arguing their position, and sometimes even answering one another explicitly, point for point. Authors on both sides of each debate relied heavily upon the rhetorical use of 'nature' to advance their arguments, exposing in the process the widening divide between two distinct early modern English perceptions of the natural world. While some clung to an Aristotelian, teleological view of nature, working on its own toward some positive and productive end, others saw nature as a passive, disordered and manipulable entity that could (and should) be improved through carefully planned human intervention. The Great Level drainage debates were thus shaped by, and helped shape in turn, the shifting understandings of nature in seventeenth-century England.

Whether to drain?

The Great Level is comprised of nearly 400,000 acres of silt and peat in eastern England, stretching across parts of the counties of Norfolk, Suffolk, Cambridgeshire, Huntingtonshire, Northamptonshire and Lincolnshire, surrounding a large North Sea bay called the Wash. The landscape is very flat, aside from a few small rises or 'isles,' and before the drainage works of the seventeenth century it was dominated by a number of meandering rivers, many of which were tidal and none of which was very efficient at carrying water from the surrounding uplands through the Fens to the North Sea. The majority of the land was flooded for at least part of the year, rendering it unsuitable for conventional cereal agriculture, and difficult to travel through on foot. The Fens were therefore inaccessible and sparsely populated (compared to the rest of England), and were generally perceived as being isolated from the rest of the realm, beyond the reach of most civil authority and thus a haven for outlaws and rebels. The sixteenth-century antiquary William Camden, in his description of Britain, portrayed the Fens as a dangerous and unhealthy place, a land in which no rational person would willingly choose to live. The flooded lands were plagued by 'the offensiue noisomnes of meres and the unholesome aire of the fennes,' which bred all manner of diseases, while the water itself 'doth sometimes in calmes and faire weather sodainly rise tempestuously, as it were into violent water-quakes to the danger of the poore fishermen'. The fenland inhabitants he described as an uncivilised people, utterly alien to the agricultural society that predominated in the surrounding higher lands: '*Fen-men, or Fen-dwellers*,' he wrote, were 'A kinde of people according to the nature of the place where they dwell rude, uncivill, and envious to all others whom they call *Vpland-men*'.[5]

Yet the pre-drainage Fens were not nearly so uninviting and unprofitable as they might at first have seemed to the wary stranger. While the floodwaters

[5] William Camden, *Britain, or a Chorographicall Description of the Most flourishing Kingdomes, England, Scotland, and Ireland, and the Ilands adioyning, out of the depth of Antiquitie: Beavtified With Mappes Of The severall Shires of England*, trans. Philémon Holland (London, 1610), pp. 491, 500.

created some real inconveniences for those who lived or travelled in the region, and certainly made conventional cereal agriculture difficult if not impossible, they also provided a number of valuable commodities that allowed an alternative agricultural economy to flourish. The principal boon derived from the intermittent flooding was abundant grassland for grazing; while permanently flooded land was a nuisance, land that was flooded for only part of the year (as in the vast majority of the Fens) afforded perhaps the best grazing land in England. In addition, the watery region also naturally yielded an abundance of water fowl, plentiful fish and eels, sedge and reeds for roof thatching, and peat for fuel. Various historians have shown that, far from being an unprofitable waste, the medieval Fens were actually quite prosperous, as is evident not only from the comparatively high tax assessments and rent values placed on them during the Middle Ages, but also from the many fine stone churches that can still be seen in the area.[6] William Camden, too, frequently made mention of the plentiful, if unconventional produce of the fenlands, and even raved about some of the local fare he feasted upon: 'All this *Tract-over* at certaine seasons, good God, what store of foules (to say nothing of fishes) is heere to be found!… the very delicate dainties, indeed, of service, meates for the Demigods, and greatly sought for by these that love the tooth so well…'.[7] Concerning the supposed unhealthfulness of living in such an area, Camden found that it was a much greater problem for strangers than for the local inhabitants, who in any case considered it a fair trade for the great abundance the land yielded in their eyes: 'As for the unhealthinesse of the place, whereunto onely strangers, and not the natives there are subiect, who live long and healthfully, there is amends made, as they account it, by the commodity of fishing, the plentifull feeding, and the abundance of turfe gotten for fewell'.[8]

Despite the Fens' productivity, however, outsiders continued to view them as a wasteland, apparently unable to conceive of a prosperous agricultural economy that was not based primarily on arable; landowners and speculators had long sought to drain them, in order to enhance still further the value of their annual rents. The first proposals to drain the whole of the Great Level as a single undertaking date from the end of the sixteenth century. In 1589, for example, the Brabanter Humphrey Bradley presented to Queen Elizabeth and her Privy Council his opinion concerning the feasibility of such a project. Familiar with contemporary drainage works in his homeland back in the Low

[6] H. C. Darby, *The medieval Fenland* (Cambridge: Cambridge University Press, 1940; 2d ed., Newton Abbot, Devon: David & Charles, 1974); Thirsk, *Peasant farming*, chap. 1. Summers, chaps. 1-2.
[7] William Camden, *Britain,* p. 543.
[8] Ibid., p. 500.

Countries, Bradley was amazed that England's plentiful wetlands were permitted to remain flooded and (to his eye) unprofitable, when he believed so much stood to be gained from them. He attributed this state of affairs to a failure 'in the minds and in the imaginations of men,' and urged his readers not to be discouraged by the apparent difficulty of such a vast enterprise.[9] When his first proposal generated no progress, he reiterated his views to the Privy Council in 1593, chiding them for their ongoing failure to exploit such potentially profitable lands: 'The improving of the fennes, then ys no miracle, yea rather unto sutch, as wth Judgmendt do consider of them, yt seamethe one of the Wonders of y^{e} Woreld, that they haue layen thus long neglected, in y^{e} midest as yt ware of the Realme, and among a nation of so politique a Gouernment'.[10]

Bradley argued that, despite the vast size of the area in question, the fenland drainage would actually be a relatively simple and inexpensive undertaking compared with similar works in the Low Countries, because the entirety of the land was above sea level; the natural drainage system therefore needed only a little well-placed assistance to drain a large area, transforming the whole region into very fertile arable. The entire project, he believed, could be accomplished within a matter of months by employing seven or eight hundred labourers to dig a single drainage channel roughly four miles long. When completed, the new drain would serve some 400,000 acres, yielding an annual net profit to the owners of at least £40,000, 'and reduc[ing] thys wildernesse to a fruictfull Soyle, better hable to nourishe in good State a hundrith thousand families, then now one thousand in want'.[11] As for the many native commodities to be had in the undrained fens, such as 'fish, birds, canes, bushes and similar other things,' Bradley was dismissive, holding them to be 'all of little worth'.[12]

Although little came of Bradley's proposals during the sixteenth century, later authors certainly agreed with his assessment. In 1629, a writer identified only as H. C. published a treatise in which he portrayed the Fens as little better than a hell on earth, whose inhabitants were eternally tormented by water

[9] Humphrey Bradley, 'Discorso sopra il stato, delle paludi, o ver Terre Inundate (volgarmente ffennes) nelle Prouincie di Nortfolcia, Huntingtona, Cambrigia, Northamtona, e Lincolnia composto par Humfredo Bradley: Gentilhuomo Brabantino…,' British Library, Lansdowne Manuscripts, 60/34, 3 December 1589. The text has been translated in Darby, *Draining*, appendix I, pp. 263-269; quotation from p. 264.

[10] Humphrey Bradley, 'A proiect ffor the drayning off the fennes, in her M^{tes} countes, off Cambridge, Huntington, Lincolne, Norfolke and Southfolke, contayning more then aight hundrith thousand Acers…,' British Library, Lansdowne Manuscripts, 74/65, 3 April 1593, fol. 180 r.

[11] Ibid., fol. 180 v.

[12] Humphrey Bradley, 'Discorso,' in Darby, *Draining*, p. 265.

instead of fire. Indeed, he argued that not a single element in the Fens could be deemed pleasant and healthy for its occupants. 'What should I speake of the health of mens bodyes,' he wrote, 'where there is no Element good. The Aer Nebulous, grosse and full of rotten Harres; the Water putred and muddy, yea full of loathsome vermine; the Earth spuing, vnfast and boggie; the Fire noysome turfe and hassocks: such are the inconveniences of the Drownings'. During the cold, wet winters, moreover, when the flooding was at its worst, the natural isolation of the place was often compounded by freezing temperatures. In an area accessible only by boat, the freezing of the flood waters meant that the poor fenlanders 'can haue no helpe of Food, no comfort for Body or Soule, no Woman ayd in her Trauell, no meanes to baptize a Child or to administer the Communion, no supply of any necessitie, sauing what those poore desolate places can afford'. Nor did the isolation of the Fens affect only those who lived there; it had for many centuries past endangered the entire realm by providing a safe haven for rebels and bandits, 'to which purpose it might serue againe, if God and the wisedome of our Gouernours were not watchfull at the Helme'.[13]

The state of the undrained Fens, then, could only be considered abysmal, especially when compared with what might be reaped there if the flood-waters were permanently removed. H. C. believed that the Fens had the potential to become 'a goodly Garden of a Kingdome; yea a little Kingdome it selfe: as much and as good ground, it is supposed, as the States of the Low-Countreys enioy in the Netherlands'. The benefits for the commonwealth that would spring from the drained lands included all manner of animals, crops, and general conveniences. As for the grazing fodder of the undrained Fens, the author was as dismissive as Bradley, calling it little more than 'ranke trash'. He took special care to point out that sheep and cattle could be supported on drained lands without fear of 'the rot', a disease that sometimes afflicted animals grazing in flooded pastures when they ate grass that had never dried out fully. Indeed, H. C. suggested that anyone seeking to preserve the status quo against the obvious benefits of a proper drainage was not looking at the situation rationally: 'some of them being not ashamed to alleadge, that by gayning of Grasse, they should loose their Reedes and Sedge, not considering the difference of their values'.[14] Other authors picked up on many of the same themes (and even some of the same language) in advocating a general drainage. Samuel Fortrey, for example, in his retrospective

[13] H. C., *A Discovrse Concerning the Drayning of the Fennes and Svrrovnded Grovnds in the sixe Counteys of Norfolke, Suffolke, Cambridge with the Isle of Ely, Huntington, Northampton, and Lincolne* (London, 1629), fol. A3 r-v.

[14] Ibid., fol. A3 v – B r, C2 v.

History or Narrative Of the Great Level of the Fenns, described the undrained region as 'an unhealthful Stagnation of putrid and muddy Waters; The Earth spungy, unfast and boggy, such as are the inconveniencies of Drown'd Lands, and yielding no considerable Profit to the Inhabitants that bordered upon it'.[15]

Even in their flooded condition, however, the Fens were not without their defenders. The anonymous author of a short pamphlet called *The Anti-Projector* boldly asserted that the oft-repeated condemnations of the Fens as unhealthy and unprofitable were based on nothing more than plain ignorance, and the arrogance of outsiders who could not imagine an economy or way of life different from their own. 'The undertakers [investors] have alwaies vilified the Fens,' he wrote, 'and have mis-informed many Parliament men, that all the Fens is a meer quagmire, and that it is a level hurtfully surrounded [flooded], and of little or no value: but those which live in the Fens, and are neighbours to it, know the contrary'. He then went on to describe in detail the rich and valuable produce of the *flooded* fens, showing that the land did not need draining to yield an agricultural bounty. First and foremost, they provided ample fodder for 'infinite number of serviceable horses, mares, and colts,… great store of young cattle,… [and] great flocks of sheep'. The livestock, of course, gave rise to a wide array of valuable commodities, from meat, milk and cheese to wool, hides and tallow. In addition to serving as grazing land, reeds and sedge naturally grew in the flooded fens, while the drier portions could even support small crops of wheat and barley.[16]

Crucially, it was the periodic flooding that made such richness possible: the flooding produced abundant grass and hay, which allowed larger herds of valuable livestock to be supported through the winter. These, in turn, provided enough manure to fertilise thoroughly the smaller patches of arable, making them extraordinarily rich and productive. Moreover, the alleged difficulty of transporting goods and people through the flood-prone region only applied to armies, and others travelling by land; for transporting goods to market, the Fens boasted an unrivalled system of water transportation, which allowed those goods to be sold more cheaply at market than if they had been carted there. With regard to some of the new crops that might

[15] Samuel Fortrey, *The History or Narrative Of the Great Level of the Fenns, Called Bedford Level, With a Large Map of the said Level, as Drained, Surveyed, & Described by Sir Jonas Moore, Knight, His late Majesties Surveyor-General of his Ordnance* (London, 1685), p. 10.

[16] Anon., *The Anti-Projector: Or The History of the Fen Project* (London?, 1646?), pp. 7-8. The author of this pamphlet may have been John Maynard; I have found a number of linguistic similarities between it and another anonymous text based upon his original speeches: *The Picklock of the Old Fenne Project: Or, Heads of Sir John Maynard his severall Speeches, Taken In Short-hand, at the Committee for Lincolneshire Fens, in Exchequer Chamber* (London:, 1650).

be cultivated on drained land, the author was every bit as dismissive as pro-drainage authors were of the Fens' natural produce. 'What is Cole-seed and Rape,' he asked; 'they are but Dutch commodities, and but trash and trumpery, and pills land, in respect of the fore-recited commodities, which are the rich Oare of the Common-wealth'.[17]

The natural prosperity of the Fens, then, far from being hindered by the floods, was actually *caused* by them. It is interesting to note that the list of commodities acquired from the flooded land, according to the author of *The Anti-Projector*, often overlaps with the list of benefits that would be reaped from the land once drained, according to H. C. – meat, wool, hides, tallow, even convenient transportation.[18] The main difference, then, between the pro- and anti-drainage positions lay not in the authors' desired goals – the agricultural prosperity of the Fens, and the benefit of the English commonwealth – but in the methods used to attain those goals, and in their attitudes toward the land itself. Whereas one author saw in the Fens a land that could never reach its full productive potential as long as it was regularly flooded, the other saw in the floods the very fount of wealth in the land. One author looked for artificial assistance to allow nature to reach heights it could not otherwise attain, while the other believed in working with nature on its own terms, and exploiting the Fens as he found them. Both authors, however, grounded their argument for prosperity in the *natural* productivity of the land in question.

The dispute between the pro- and anti-drainage factions was often cast in terms of the 'natural' state of the Fens. Some pro-drainage authors even argued that the land's flooded condition was not in fact its 'natural' situation, on the grounds that it had not always been that way; the drainage project would thus serve to restore the land to an earlier state of natural productivity. William Camden, the antiquary, was perhaps the first to look back to the medieval chronicler William of Malmsbury, who recalled a time when at least some part of the Fens was prosperous farmland, quoting him: '*Heere shall you find the earth rising some where*

[17] *The Anti-Projector*, pp. 7-8. Coleseed and rapeseed were increasingly popular market crops in seventeenth-century England. They were cultivated for their oil, which was used for a variety of purposes, including cloth-dyeing and soap-making. Many Englishmen hoped that growing such crops domestically would end English dependence on foreign supplies of oil; as it happened, both plants grew especially well on newly drained lands. Others were more critical, associating the crops with unpopular monopolies and 'projectors', investors who often had a reputation for dangerous financial speculation and corruption. See Joan Thirsk, *Economic policy*, and idem, *Agrarian history*, chap. 16.

[18] See H. C., *Discovrse,* fol. [A4 v]. I am grateful to Will Ashworth for pointing out that oil-producing plants such as rapeseed and coleseed, which grew best on drained lands and were most closely associated with England's burgeoning market agricultural economy, are prominent among the valuable commodities *not* mentioned by both sides.

for apple trees, there shall you have a field set with Vines, which either creepe upon the ground, or mount on high upon poles to support them. A mutuall strife there is betweene Nature and husbandry, that what the one forgetteth; the other might supply and produce'.[19] Likewise, Walter Blith, author of the well-known agricultural 'how-to' text *The English Improver Improved*, argued that draining the Fens would actually return them to 'their *naturall* fruitfulnesse,' or perhaps even bring them 'to a more Supernaturall Advance than they were ever known to be'.[20] According to this view, active human intervention in the Fens was the only way to restore their fruitful natural condition.

Some authors went so far as to compare the flooded Fens to a sick patient, in dire need of medical care to relieve a potentially fatal condition. Another semi-anonymous author, I. L., cast himself as a physician in arguing in favour of the drainage: 'First then, (imitating a skilfull Physitian who first maketh a diligent scrutinie into the cause, and malignant qualities of a disease, ere he meddle with the cure) I will shew you the great defects and maladies the body of this Kingdome long hath, and still doth, labour with; next, how they may be repaired and cured by this worke of well drayning and imbanking surrounded lands'.[21] H. C. also used the analogy of a sick patient in his treatise, comparing the inefficient fenland rivers to a blocked urinary tract, which backs urine up into the kidneys and the blood stream, eventually drowning the victim in his own fluids unless the blockage is removed. Likewise, he reasoned, when the outfalls of the fenland rivers were blocked up, the waters soon filled all the rivers and drains, and then spilled over to flood the whole land, essentially drowning it.[22]

Not to be outdone, some anti-drainage authors also used medical analogies, though they referred more to the tendency of seventeenth-century physicians to make things worse in order to turn the argument on its head. In asserting that new, artificial drains could only be inferior to those devised by Nature herself, John Maynard used the human body as a model:

> The old Dreynes are as the naturall sinks, or rather Vent of the Body of the Fens; Suppose a mans fundament were stopped, and that a hundred Issues were made in the body, the whole masse of blood would quickly be corrupted, and the body woould breake out in botches and biles.

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[19] William Camden, *Britain,* p. 494.

[20] Walter Blith, *The English Improver Improved or the Svrvey of Hvsbandry Svrveyed. Discovering the Improueableness of all Lands: Some to be under a double and Treble others under a Five or Six Fould. And many under a Tenn fould, yea Some under a Twenty fould Improuement* (London, 1652), p. 16; my emphasis.

[21] I. L., *A Discourse Concerning the Great Benefit of Drayning and imbanking, and transportation by water within the Country* (London, 1641), fol. A3 r.

[22] H. C., *Discovrse,* fol. C3 r.

So stop up the old Sewers, you will quickly perceive the sores or Quagmires will increase; and whereas there is but one Acre now hurtfully surrounded [by water] were the old Draines duly scowred, if they be stopped there will be tenne.[23]

The natural healthiness of the human body, then, could be used either to support or to ridicule the drainage projects – were the drainers skilled physicians, restoring balance and health to a dying land, or were they mere quacks, more likely to kill than cure the patient?

Along with the purported 'naturalness' of the Fens, in either their flooded or drained state, divine mysteries were also invoked by each side to support its position. William Camden explained that one common objection to draining the Fens was that no *permanent* drainage could ever be effected there. The flood waters might be pushed back, but they would always return – that being God's manifest will when he created the land in such a state, 'So that many thinke it the wisest & best course according to the sage admonition in like case of *Apollo* his Oracle, *Not to intermeddle at all with that which God hath ordeined*'.[24] Other anti-drainage authors made similar arguments; one anonymous writer asserted that the Fens were 'alwaies Fennes,… even soe ordayned by God,' and that the only way this could be challenged was through 'Coniuration' of evil spirits to subvert God's will.[25]

Those authors in favour of the drainage project, of course, argued the contrary. Thomas Fuller, pursuing a local tangent in his history of Cambridge University, considered the view that 'It is therefore a *Trespasse* on the *Divine Prerogative*, for *Man* to presume to give other *Bounds* to the *water*, then what God hath appointed'. He answered that this might apply to the ocean, which is uncontrollable, 'But it is a false and a lazy principle, if applied to *Fresh-waters*, from which *humane Industrie* may, and hath rescued many considerable parcels of ground'.[26] Likewise, H. C. argued that it was God Himself who had shown mankind what might be accomplished with marshy land, once properly drained, and that it would therefore be unwise to ignore such divine providence.[27] In this view, the flooded land represented a divine challenge to the industry and ingenuity of mankind, to complete God's efforts to separate the water from the land. Indeed, William Dugdale, in his highly partisan history of the Fen

[23] Anon., *The Picklock of the Old Fenne Project: Or, Heads of Sir John Maynard his severall Speeches, Taken In Short-hand, at the Committee for Lincolneshire Fens, in Exchequer Chamber* (London, 1650), p. 14.
[24] William Camden, *Britain,* p. 492; original emphasis.
[25] Quoted in Frances Willmoth, *Sir Jonas Moore,* p. 93.
[26] Thomas Fuller, *The History of the University of Cambridge, since the Conquest*, printed with *The Church-History of Britain, From the Birth of Jesus Christ Untill the Year MDCXLVIII* (London, 1655), p. 70.
[27] H. C., *Discovrse,* fol. B2 r – v.

drainage, cited God Himself as the first land drainer, quoting from no less an authority than the Book of Genesis:

> That works of Drayning are most antient, and of divine institution, we have the testimony of holy Scripture. *In the beginning God said, let the waters be gathered together, and let the dry land appear; and it was so: And the Earth brought forth grass, and herb yielding seed, & the fruit-tree yielding fruit after his kind; and God saw that it was good.*
> Again, after the Deluge, it was through the divine goodness, that *the waters were dryed up from off the Earth, and the face of the ground was dry.*[28]

Both the pro- and anti-drainage factions, then, believed that the core of their position lay in the 'natural' state of the land in question, though each side had a different understanding of how nature ought to be approached. Those promoting the drainage saw nature as an imperfect, passive entity, capable of being manipulated in order to yield better results. In portraying the Fens as being sick, broken, or somehow incomplete, they argued that human intervention could and should be used to improve their natural condition. Drainage opponents countered that the Fens were not deficient, but were simply productive in ways that might not conform to prevailing English ideas concerning agriculture. Any attempt to remove the floodwaters from the Fens, they believed, would spoil a natural source of prosperity in return for short-sighted and short-lived gains, and would be unlikely to succeed in any case. Competing ideas about what the Fens were and what they ought to be, as well as man's proper relationship to the natural world in general, drove the debate.

How to drain?

Even among those who agreed that draining the Fens was a good idea, there was little consensus as to how best to go about it. Once again, the argument was often framed in terms of nature – just how badly broken was the natural system of drainage, and how much human manipulation would be required to fix it? While various observers disagreed about their relative importance, most nevertheless concurred regarding the several factors responsible for the Fens' poor drainage. As water drains from the uplands surrounding the Fens into the North Sea, obviously it must flow through the Fens to do it. Because the Fens are so flat, the many rivers that flow through them are slow and meandering, so that the water draining rapidly into the Fens from above can drain out again

[28] William Dugdale, *The History of Imbanking and Drayning of Divers Fenns and Marshes, Both in Forein Parts, and in this Kingdom; And of the Improvements thereby. Extracted from Records, Manuscripts, and other Authentick Testimonies* (London, 1662), p. 1.

only very slowly; during the wet English winters, this alone is enough to cause flooding. When the rivers overflow their banks, the flatness of the land ensures that the flood waters will cover a very large area. The rivers' slow current also causes them to silt up, as eroded upland soil settles to the bottom, making the riverbeds ever shallower and so even more likely to overflow. Moreover, the seventeenth-century Fens were only a few feet above sea level, which meant that the rivers' outflows could be backed up for a considerable distance upriver at every high tide, further hindering the waters' drainage, and depositing even more silt (this time from the ocean) in the rivers' mouths. In fact, a great portion of the Fens themselves were actually composed of collected silt from the rivers and the Wash, an expanding but marshy landscape through which the lazy rivers had to find new paths to the sea.[29] The question for drainage proponents was not whether such land could ever be made to drain efficiently, so that the upland waters would empty into the North Sea without lingering to do any damage along the way; all those supporting the drainage project assumed that such a thing was feasible. The question was how much and what kind of help nature would need to be given in order to accomplish it, and the answer was far from obvious.

Humphrey Bradley, in his early proposals, seems to contradict himself in this regard. Having concluded in 1593, 'upon vewe and exact Leuells taken,' that the Fens lay 3-5 feet above the level of a high tide, and more than fifteen feet above a low tide, there was no reason why they should not have sufficient descent 'to voide ye surplusaege of waters, more then enough'. The problem was simply that the natural rivers were silted up; if they were to be dredged and properly maintained, the water would then do what water naturally does – flow downhill to the sea, 'So that what furtherance, nature canne afford, thyse fennes have yt'.[30] This assertion accords with Bradley's statement in 1589, that 'the enterprise does not need anything but some assistance given to nature, by which the waters can be led through channels of convenient depth and width, to the outlets, that are at hand… there to empty themselves into the sea'.[31] However, later in that same proposal, Bradley also hinted at a more aggressive and radical solution. In discussing his proposed works in detail, Bradley wrote that 'the most expedient and only way to redeem the lands from their waters is to draw off the waters by directing them along the shortest tracks to the greatest outfalls, in canals dug of such width and depth as can serve to make the waters run out into the sea'.[32] This proposal called not

[29] Joan Thirsk, *Peasant farming*, chaps. 1 & 5; H.C. Darby, *Medieval Fenland*, chap. 2.

[30] Humphrey Bradley, 'A proiect,' fol. 180 r.

[31] Humphrey Bradley, 'Discorso,' translated in H.C. Darby, *Draining,* pp. 264-65.

[32] Ibid., p. 269.

merely for maintaining the old rivers, but for constructing some entirely new, more efficient rivers, which would vent the excess water more rapidly than the winding natural rivers could match. This contradiction between natural and man-made drainage channels would set the terms of the debate for the next century and beyond.

In 1638, the Dutch émigré Cornelius Vermuyden submitted his own plan for draining the Great Level of the Fens to King Charles I; the plan was published in 1642, at the king's behest. More than any other single person, Vermuyden was the architect of the scheme ultimately used to drain the Great Level and other fenland regions. Having come to England around 1620, Vermuyden had drained (or attempted to drain) smaller wetland areas in various parts of England – he became a royal favourite, and was knighted in 1629 for his work in draining the king's estates in Hatfield and the Isle of Axholme in Lincolnshire – but the Great Level was where he hoped to secure his reputation and fortune. During the 1630s, Vermuyden had already achieved a partial drainage of the Great Level, turning it into 'summer ground' that would support some crops, though still flooding in the winter. This ambiguous state of affairs was deemed insufficient by Vermuyden's English employers, including the king, and so his new proposal of 1638 was a far more ambitious one: to turn the Great Level into 'winter ground', free from flooding in every season.[33]

In his proposal, Vermuyden stressed the vast size of the Great Level, and the difficulty of draining the entire region by conventional means. He admitted that the normal course for draining such lands would be to dredge the extant rivers to make them deeper, and build up their banks to prevent overflowing while waiting for the water to drain itself naturally; but he did not believe this approach could work in the Great Level, given the huge expense and uncertainty of success. The new, enlarged riverbanks would have to be constructed alongside more than two hundred miles of river, over low and nearly level ground, using only the loose and peaty soil locally available, and then be perpetually maintained; the annual maintenance alone would cost a fortune, and they might not even work in the first place. Vermuyden thus sought a different and more radical approach: '[T]o avoyd these and many more inconveniences,' he wrote, 'I find it best to leade most of the Rivers about another way…'[34]

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[33] For Vermuyden's biography and career in England, see L. E. Harris, *Vermuyden and the Fens: a study of Sir Cornelius Vermuyden and the Great Level* (London: Cleaver-Hume Press, 1953); H.C. Darby, *Draining*, chap. 2; J. Korthals-Altes, *Sir Cornelius Vermuyden: the lifework of a great Anglo-Dutchman in Land-Reclamation and Drainage* (London: Williams & Norgate, and The Hague: W. P. Stockum & Son, 1925); and Samuel Smiles, *Lives of the Engineers*, 5 vols., Vol. 1: *Early Engineering* (London: John Murray, 1874), chap. 2.

[34] Cornelius Vermuyden, *A Discourse touching the Drayning the Great Fennes, Lying Within the several Covnties of Lincolne, Northampton, Hintington, Norfolke, Suffolke, Cambridge, and the Isle of Ely, as it was presented to his Majestie* (London: 1642), p. 9.

Rejecting the old rivers as unsalvageable, Vermuyden proposed instead that a series of new, straight riverbeds be carved through the landscape. These artificial rivers, if surveyed and sighted carefully, could take full advantage of the limited downward gradient the Fens had to offer, and would thus vent more water into the Wash at a greater velocity; this, in turn, would enable the rivers to remove more of the silt that threatened to accumulate both in the riverbeds and at the outflows. The new rivers would be given high banks, but these would be set back at some distance from the riverbeds, so that the rivers would have some room to swell before the water threatened the surrounding lands. The area in between the riverbed and the new banks could be used for pasture when the water was low, and would be well worth the sacrifice to spare the rest of the Level during flood conditions. Sluices would also be built near the outflows, to help keep the ocean tides from hindering the rivers' flow and depositing too much extra silt in the riverbeds. Vermuyden's plan, in short, was to consolidate the many rivers of the Great Level into a smaller network of artificial, perfectly straight drainage channels, which would work more effectively at draining water and scouring silt, and be easier and cheaper to maintain over time. It represented quite a radical re-conception of the Level's existing drainage system, but Vermuyden presented his plan as a means of recreating in the Fens the superior *natural* drainage of the surrounding upland areas, with their steeper descent: 'I resolve to imitate nature (as much as can) be [sic] in the upland Countries'.[35]

Other drainage advocates agreed with Vermuyden that only man-made rivers could ever drain the Great Level effectively, even though they disputed some of the specific points of his plan. William Dodson, for example, a colleague and rival of Vermuyden's, published a proposal that differed in detail from Vermuyden's but shared the same basic philosophy. In order to keep maintenance costs under control on the new drainage system, Dodson advocated finding the best rivers in the Fens (those with the greatest natural slope), augmenting them, and eventually combining all the fenland rivers so that they shared a single, common outfall. This, he believed, would make the fullest use of the Fens' limited natural slope, while the greater volume of water vented in one place would help to prevent silting. Like Vermuyden, he too asserted that in his artificial drainage scheme he was merely recreating a more 'natural' system of drainage, such as might be observed in the surrounding uplands. 'I shall extract no other cure for [the land's] present Distemper, then what Nature her self hath appointed for a Remedy,' he declared, by relying upon

[35] Ibid., pp. 12-13 (fol. [B4 v] – C r). Although both the text and folio signatures were in order in the volume I examined, the page numbers were badly out of sequence in places; for the sake of clarity, I have therefore provided folio signatures as well.

'those Rivers which Nature hath appointed to conduct the supernumerary Waters to [the sea]'.[36]

Not all drainage proponents were convinced that digging new, straighter rivers was the best solution, however; many believed that the fenland's existing rivers would work just fine, given a little cleaning and dredging. John Westerdyke, a fellow Dutchman called in to consult about Vermuyden's drainage scheme, criticised his radical approach. Westerdyke argued that if the goal was to keep the rivers from overflowing, all that was necessary was to raise their banks sufficiently, and ensure that their outfalls were not blocked by silt: 'And this being apparently the *disease*, therefore the *confining* these rivers within *sufficient banks* must consequently in reason be the *cure*…'. So unimpressed was he with one of Vermuyden's newly constructed rivers, already half completed, that he wondered whether that work was even salvageable: 'it is a disputable *question*, notwithstanding all the charge bestowed on the banks of that [Bedford] river, whether it be not yet the *best course to desert it…'*.[37]

Edmund Scotten, another harsh critic of Vermuyden, also thought very little of his plan to carve new rivers through such uncertain ground. Pointing out that Vermuyden himself had acknowledged that his plan was rather unorthodox, he also took him to task for being too vague about the specifics of his proposal. In a highly provocative tone, he asked 'Whether in stead of imitating nature… doth he [Vermuyden] not in this and divers other darke passages rather imitate the popish Clergy, who keepe men as ignorant as they can, that they may the more easily deceive them, and leade them whether they list'.[38]

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[36] William Dodson, *The Designe For the present Draining of the Great Level of the Fens, (called Bedford Level) Lying in Norfolk, Suffolk, Cambridgeshire, Huntingtonshire, Northamptonshire, Lincolnshire, and the Isle of Ely. As it was delivered to the Honourable Corporation for the Draining of the said Great Level, the 4th of June, 1664. As Also, Several Objections answered since the Delivery of the said Designe: with Objections to the Designe now in agitation. And as for the New Works intended in this Designe, appears in the annexed Map; and the Charge of the whole Calculated* (London, 1665), p. 1.

[37] William Elstobb, *Observations on an Address to the Public, Dated April, 20, 1775, Superscribed Bedford Level, and Sign'd Charles Nalson Cole, Register…* (Lynn, 1776), p. 68. Westerdyke's original manuscript criticism of Vermuyden is now lost; Elstobb, a harsh critic of Vermuyden's scheme over a century later, was one of the last commentators to see the Westerdyke report, quoting liberally from it in his own assessment of the Great Level drainage.

[38] Edmund Scotten, *A Desperate and Dangerovs Designe Discovered Concerning the Fen-Countries, By A faithfull friend, who as soone as it came to his knowledge, hath taken some pains, not only to discover, but to prevent the same; By order of the Committee for the Fenns. Published for the Common-good, and in all humility presented to the High Court of Parliament. And in particular to some Noble Personages especially interessed* [sic] *and concerned therein* (London, 1642), pp. 16-17. To compare Vermuyden with 'popish' clergy had both religious and political implications in 1642, as perceived royal tyranny and Catholic religious tendencies were increasingly linked in the minds of the Puritan-leaning Parliamentary forces during the lead-up to the civil war. It was, in short, a profound insult.

In contrast, Scotten favoured the much simpler, clearer, and to his mind more natural solution of dredging the existing rivers to make them deeper and raising their banks against high waters in the winter: 'Let Rivers be made large and deepe,' he insisted, 'and there will be matter enough arising thereout with the indikes to make high banks, neere on each side of the Rivers'.[39] As far as he was concerned, Vermuyden's convoluted and artificial drainage scheme marked him as a charlatan and a fraud.[40]

Others questioned whether a Dutchman, whatever his experience with land drainage elsewhere, was an appropriate choice to accommodate English needs. H. C., for example, though a strong supporter of the Great Level drainage, wondered whether Dutch techniques were really a suitable match for the English Fens. Dutch methods might work very well, in their place, but England's natural circumstances were different. Unlike the Dutch wetlands, the English Fens were entirely (if only slightly) above sea level, and so should not need any elaborate schemes to drain them. Instead, the best approach would be to follow 'the remedy which is meerely Naturall,' enlarging and maintaining the existing rivers so that they might drain the land as effectively as possible.[41]

Even among those who supported the drainage project, then, there was considerable disagreement about the best course of action, with the 'naturalness' of the solution being a principal touchstone for success. As with the debate about whether or not to drain the land in the first place, both sides were able to argue that their approach was more in accord with natural principles, although they did not agree about which principles ought to be considered 'natural'. While some held that there was no need to alter the fenland drainage system established by nature, so long as it was properly maintained, others believed that constructing entirely new, artificial drainage channels would allow the Fens to drain more 'naturally', according to the prevailing patterns observed in the surrounding uplands. The dispute was not simply about natural vs. artificial rivers, therefore, but rather how much artificial assistance was required to allow nature to act more effectively on its own. Did the existing drainage system need just a little human attention to attain its own natural ends? Or was a more aggressive and sustained human intervention necessary to reshape the Fens in accordance with the more efficient natural drainage system of the surrounding uplands? The paradox of helping nature to behave more 'naturally' through artificial means was sometimes apparent in the treatises, as for example in H. C'.s stated preference for always following

39 Ibid., p. 24.
40 Ibid., pp. 22-23.
41 H. C., *Discovrse,* fol. C2 r-v.

‘the guidance of Nature,’ despite having to ‘adde Art as a hand-mayd vnto it’.[42] Nevertheless, divergent understandings of the natural world allowed each side to use ‘nature’ to support its own point of view.

The changing nature of ‘nature’

The rhetorical uses of ‘nature’ in the fenland debates must be seen in the context of a larger contemporary disagreement among early modern natural philosophers about how nature actually worked.[43] According to the traditional Aristotelian worldview, which had predominated in European natural philosophy for centuries, nature was understood to be fundamentally teleological. Everything in Aristotle’s world was defined by a ‘final cause’, which dictated its reason for being; there was always a specific place it was supposed to be and a precise role it was supposed to play there. When displaced for any reason, things in nature would seek to fulfil their natural potential by returning to their proper place of their own accord – this was how Aristotle explained natural motion. For Aristotle, the universe was thus an inherently conservative and orderly place, the basic coherence of which was always preserved by the natural tendency of things to return to where they belong. In such a world, there could be little or no random or disordered motion; whatever nature did, it did for a reason. Human beings might interfere with this process – throwing a stone high into the air, for example, contrary to its natural tendency to fall toward the centre of the earth – but such motion was considered to be violent and unnatural, and sooner or later teleological natural motion would reassert itself and order would be restored. From the Aristotelian perspective, draining the Fens using man-made rivers was pure folly – the Fens were flooded for a reason, as part of God’s plan for Creation; this condition could not be permanently altered though human action; and the only rational approach would be to accept the land as it was and make the best of it.

During the seventeenth century, however, the Aristotelian worldview was successfully challenged by a new generation of natural philosophers associated with the ‘Scientific Revolution’, including Francis Bacon, Rene Descartes, Thomas Hobbes and Robert Boyle. Although these men did not adhere to a

[42] Ibid., fol. C2 r-v.

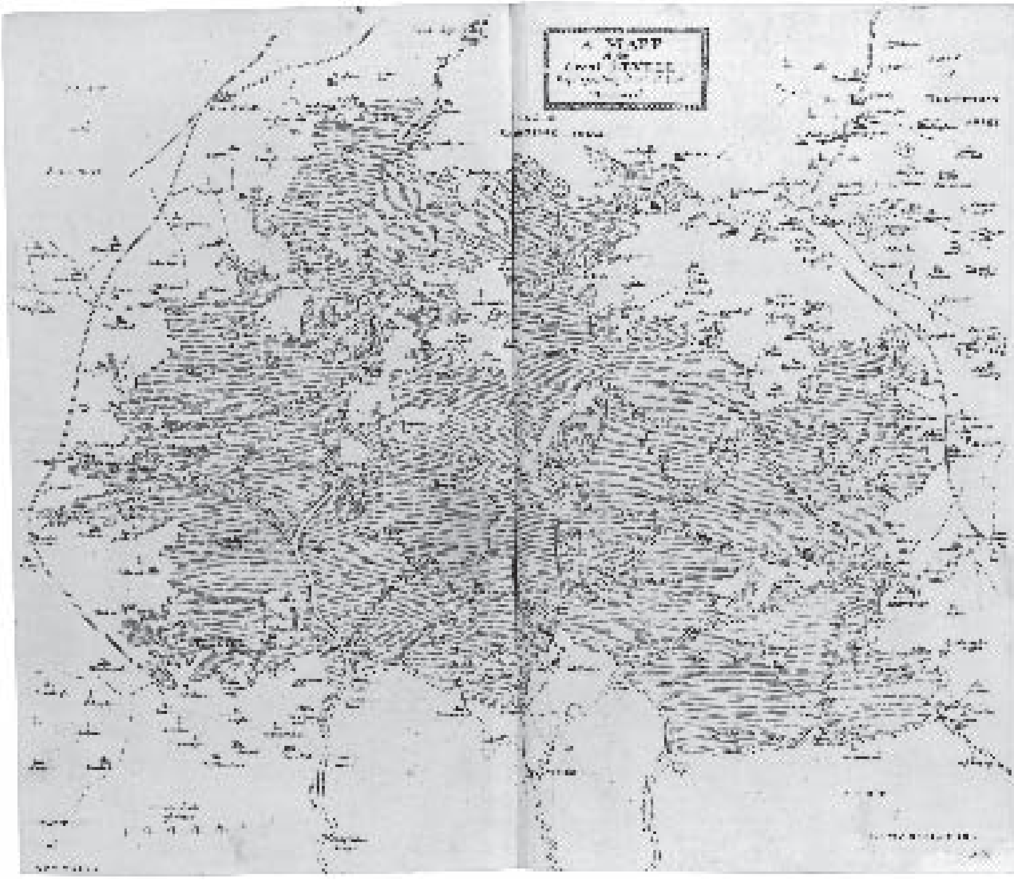
[43] On the seventeenth-century shift from an Aristotelian, teleological natural philosophy to a mechanical philosophy, see Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996), chap. 1; Peter Dear, *Revolutionizing the sciences: European knowledge and its ambitions, 1500-1700* (Princeton, NJ: Princeton University Press, 2001), chaps. 3-5; and Thomas A. Spragens, Jr., *The politics of motion: the world of Thomas Hobbes* (Lexington: The University Press of Kentucky, 1973), chap. 4.

single philosophical system and often disagreed with one another, their views of nature did share some key elements, among the most important of which was their rejection of teleology in the natural world. According to the new natural philosophy, things in nature did not behave the way they did because they were trying to fulfil some inherent purpose; rather, they behaved according to a set of fixed natural laws governing all matter in the universe. There was no deeper meaning or final cause behind their motions, only blind and passive obedience to the natural laws. Perhaps the most successful of the anti-Aristotelian approaches to understanding nature was mechanical philosophy, in which the entire universe was to be interpreted simply as matter in motion. These elements might be analysed and predicted using the laws of mechanics, but the universe did not operate according to occult 'final causes' any more than a billiard ball did as it bounced around on the table surface. According to this view, nature was a reactive and often turbulent place; order might be imposed upon it, but only through the persistent effort of rational human beings to modify and manipulate the world around them. In such a world, the Fens were not flooded for any higher purpose, but merely because their rivers did not work very well; this situation could be corrected through active human intervention, and should be.

The various protagonists in the Fen drainage disputes did not explicitly frame their arguments in terms of Aristotelian teleology or mechanical philosophy, but the echoes of the larger philosophical debate can be heard in their contradictory uses of 'nature' to ground their arguments, and in the divergent views of the natural world that these arguments imply. Those advocating minimal human intervention in the Fens asserted that the region was flooded for good reason, and must be taken on its own terms. Those seeking to drain the Fens by whatever means necessary viewed the landscape as a passive and chaotic entity, which human beings might improve through their ingenuity and hard work – only artificial effort could reclaim and redeem a disordered nature, for it would not do so on its own.[44]

The drainage undertakers, then, did not see themselves as working within an existing, immutable natural landscape, but creating a brand new landscape, the economic potential of which was virtually limitless. In a larger sense, their task was to create order and reason where none had existed before – an attitude nicely summarised in the turgid poetry of an anonymous pro-drainage lyricist:

44 Seventeenth-century Dutch land drainers shared a similar attitude; for a contemporary example of a Dutch drainage project, see the essay by Alette Fleischer, in this volume.



Ill. 15. 'A Mapp of the Great Levell, Representing it as it lay Drowned,' from William Dugdale, *The History of Imbanking and Drayning of Divers Fenns and Marshes*…, facing p. 375. The original measures 380 x 330 mm. By permission of the Houghton Library, Harvard University.

Ill. 16. 'The Map of the Great Levell Drayned,' from William Dugdale, *The History of Imbanking and Drayning of Divers Fenns and Marshes*…, facing p. 416. The original measures 375 × 289 mm. By permission of the Houghton Library, Harvard University.

I sing Floods muzled, and the Ocean tam'd,
Luxurious Rivers govern'd, and reclaim'd,
Waters with Banks confin'd, as in a Gaol,
Till kinder Sluces let them go on Bail;
Streams curb'd with Dammes like Bridled, taught t'obey,
And run straight, as if they saw their way.

I sing of heaps of Water turn'd to Land,
Like an *Elixir* by the Chymists hand
Of Dropsies cur'd, where not one Limb was sound,
The Liver rotted, all the Vitals drown'd.
No late discovered Isle, nor Old Plantation
New Christned, but a kind of New Creation.[45]

The changes wrought upon the landscape of the Fens in transforming them from soggy, common grazing land into discrete, enclosed lots of valuable arable were profound. New crops such as rapeseed, coleseed and hemp, as well as wheat and barley, began to grow in neatly ploughed rows where sheep had safely grazed for generations.

Beyond the physical changes to the land, the new, orderly landscape was also rhetorically represented in several contemporary maps of the region. In his partisan history of English land reclamation efforts, William Dugdale understood the propaganda power of maps; he included several in his text, but none more arresting than the before-and-after depictions of the Great Level. In his first map, 'A Mapp of the Great Levell, Representing it as it lay Drowned,' Dugdale sought to convey at a glance just how much of the landscape had been dominated by flood waters.[46] (Ill. 15) The most noticeable feature of the map, by far, is the grey shading that shows the vast expanse of flooded lands across the Great Level – in fact, the viewer might be forgiven for mistaking the entire region for a single, giant lake, a conclusion reinforced by the very slight difference in shading used to depict actual meres and lakes. A number of small villages are represented, as well as a few larger market towns, but nearly all of these appear within a few tiny patches of white in a sea of grey: the 'isles' dotting the massive flooded area. Other than the towns and villages, and perhaps a few small bridges, there is virtually nothing about this landscape that looks man-made. This is a region over which nature has full sway, irrational and disorderly, uncontrolled and apparently uncontrollable.

45 Anon., 'A True and Natural Description of the Great Level of the Fenns,' stanzas 2-3, printed with Fortrey, *History,* p. 71.

46 William Dugdale, 'A Mapp of the Great Levell, Representing it as it lay Drowned,' in *History,* facing p. 375.

The other prominent features of this map are the winding rivers that snake through the flooded landscape, with little apparent rhyme or reason. Even the few rivers that were actually man-made (the remnants of medieval drainage efforts) appear accidental, as if they somehow found their own path through the muck.

This map was meant to be compared with its companion of the same region, 'The Map of the Great Levell Drayned'.[47] (Ill. 16) The dominant feature of this map, without question, is the network of surveying boundaries scattered everywhere throughout. Towns and villages are depicted, but all of them (even the larger towns) are small and schematic; the natural rivers are so relegated to the background that they are actually difficult to spot. What leaps out at the viewer is the intricate, web-like geometry of the newly surveyed lands, parcelled out and allotted to investors after they had been drained. If the previous map made the whole region look like an enormous lake, this one makes it look more like a city street-plan. If the first map depicted the perils of a disordered and uncontrolled nature, this map illustrates man's triumph over nature, imposing order through cleverness, labour, and persistence. Beyond draining the land, this map is also about surveying and exploiting it, controlling the landscape in every conceivable way.

An even more visually impressive depiction of man's power over the drained Fens may be seen in the enormous, coloured wall map produced by Jonas Moore, principal surveyor of the joint-stock company organised to build and maintain the drainage works, the Bedford Level Corporation. Intended to convey the stunning achievements of the company's investors, the dominant features of this map are certainly the two massive artificial rivers that cut long, blue gashes through the intricately surveyed landscape.[48] (see illustration 14 at the front) The new rivers seem to serve as two giant arrows, or daggers, aimed toward the North Sea – indeed, the very straightness of them is itself rhetorical, a promotion of the company's (Vermuyden's) aggressive approach in building straighter, more direct outflows. These two artificial rivers point directly, unremittingly toward the sea, unlike any natural river in the area, a mark of the company's profound success in imposing rational order upon the natural landscape. Other than these two anomalies, the viewer is struck by how little

47 Ibid., facing p. 416.

48 Jonas Moore, *A Mapp of ye Great Levell of ye Fenns extending into ye Covntyes of Northampton, Norfolk, Suffolke, Lyncolne, Cambridg & Huntington & the Isle of Ely as it is now drained, described by Sr Jonas Moore Surveyr genll* ([London], [c. 1706]), printed and sold by Christopher Browne, London. This is the third edition of the map; the first was printed in 1658. The copy I examined in my research, housed in the British Library, is hand colored, with blue used to represent water, red for the parcels of formerly common land now claimed by the Bedford Level Corporation, and yellow for parcels that remained common lands.

blue remains within the region depicted – the waters have been all but entirely restricted to the new drainage channels designed and constructed by the company. The former, natural riverbeds are difficult to discern, and only a few isolated meres and ponds still dot the area, which is otherwise filled with surveyed plots of land, each of which is carefully labelled with its size, and coloured red or yellow to indicate whether it is claimed by the company's investors in recompense or left to the inhabitants as common land. Even more than Dugdale's map, which was based on Moore's much more detailed survey, this map was meant to illustrate the Bedford Level Corporation's utter dominance over the unruly Fens, and more generally, man's ability to bend nature to his will through reason and hard work.[49]

Conclusion

The predominant understanding of nature was in a state of flux in seventeenth-century England, between the organic, teleological view of Aristotelian natural philosophy and the reactive, mechanistic view of Aristotle's early modern challengers; the clash between the two sides had practical consequences well outside the bounds of natural philosophy itself. As mechanical philosophers succeeded in banishing teleology from their understanding of the natural world, they depicted nature instead as reactive and malleable, lacking any intrinsic coherence yet open to the imposition of reason and order by human beings. The contemporary drainage of the Great Level, and the other Fen drainage projects, represented the tangible triumph of human reason over natural turmoil, the rational redesign and recreation of a natural landscape to make it conform better with the economic needs and goals of the commonwealth. The English Fens, where life was once dominated by the unusual circumstances of an unruly natural landscape, were to be transformed into the consummate expression of rational control of the natural world.

This new perception of nature, in which mankind's dominion was expected to grow ever stronger and more complete, was prevalent throughout seventeenth-century English natural philosophy. Francis Bacon, most prominently, asserted that a true understanding of nature and the ability to manipulate it for profitable ends were to be equated – the latter was the clearest sign that the former had at last been achieved.[50] Likewise, the interests and activities

[49] For an excellent discussion of the rhetorical power of maps and surveys of the drained Fens, see Frances Willmoth, *Sir Jonas Moore,* chap. 3.

[50] For a discussion of Bacon's equating of natural philosophy and practical utility, see Paolo Rossi, *Philosophy, technology, and the arts in the Early Modern era,* trans. Salvator Attanasio (New York: Harper

of the early Royal Society of London were ostensibly devoted to obtaining not just a fuller understanding of the natural world, but a more practically useful one, in order to produce greater benefits for mankind.[51]

Crucially, however, such philosophers also held that an incomplete understanding of nature could only result in an incomplete control over it. Back in the Fens, even after the official completion of the drainage works, parts of the Great Level continued to suffer minor to moderate flooding, and further efforts to improve the drainage continued well into the eighteenth century. After the limitations and shortcomings of the new, artificial drainage system had become unpleasantly apparent, later critics argued that an insufficient understanding of nature was to blame. Thomas Badeslade, a surveyor and engineer called upon in the 1720s to determine precisely how the drainage had gone wrong, wrote that any future drainage scheme must be 'Founded upon *self-evident Principles* in *experimental Philosophy* and *practical Mathematics*,'[52] with a particular consideration for 'Experiments and Reasons agreeing with Sir Isaac Newton's Theory of the Tides'.[53] After nearly a century, draining the Fens was still perceived to be a matter of manipulating the natural world according to principles learned from nature itself.

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and Row, 1970); idem, *Francis Bacon: from magic to science*, trans. Sacha Rabinovitch (Chicago: University of Chicago Press, 1968); Antonio Pérez-Ramos, *Francis Bacon's idea of science and the maker's knowledge Tradition* (Oxford: Clarendon Press, 1988); and Eric H. Ash, *Power, knowledge, and expertise in Elizabethan England* (Baltimore: The Johns Hopkins University Press, 2004), chap. 5.

[51] See, for example, Thomas Sprat, *The History of the Royal-Society of London, For the Improving of Natural Knowledge* (London, 1667).

[52] Thomas Badeslade, *A Scheme for Draining the Great Level of the Fens, Called Bedford-Level; And for Improving the Navigation of Lyn-Regis* (London, 1729), title page; original emphasis.

[53] Quoted in Frances Willmoth, *Sir Jonas Moore,* pp. 99-100.

Primary sources

Anon., *The Anti-Projector: Or The History of the Fen Project* (London?, 1646?).

Anon., *The Picklock of the Old Fenne Project: Or, Heads of Sir John Maynard his severall speeches, Taken In Short-hand, at the Committee for Lincolneshire Fens, in Exchequer Chamber* (London, 1650).

Badeslade, Thomas, *A Scheme for Draining the Great Level of the Fens, Called Bedford-Level; And for Improving the Navigation of Lyn-Regis* (London, 1729).

Blith, Walter, *The English Improver Improved or the Svrvey of Hvsbandry Svrveyed. Discovering the Improueableness of all Lands: Some to be under a double and Treble others under a Five or Six Fould. And many under a Tenn fould, yea Some under a Twenty fould Improuement* (London, 1652).

Bradley, Humphrey, 'Discorso sopra il stato, delle paludi, o ver Terre Inundate (volgarmente ffennes) nelle Prouincie di Nortfolcia, Huntingtona, Cambrigia, Northamtona, e Lincolnia composto par Humfredo Bradley: Gentilhuomo Brabantino…'. British Library, Lansdowne Manuscripts, 60/34, 3 December 1589.

—, 'A proiect ffor the drayning off the fennes, in her M^{tes} countes, off Cambridge, Huntington, Lincolne, Norfolke and Southfolke, contayning more then aight hundrith thousand Acers…,' British Library, Lansdowne Manuscripts, 74/65, 3 April 1593.

Camden, William, *Britain, or a Chorographicall Description of the Most flourishing Kingdomes, England, Scotland, and Ireland, and the Ilands adioyning, out of the depth of Antiquitie: Beavtified With Mappes Of The severall Shires of England*, trans. Philémon Holland (London, 1610).

Dodson, William, *The Designe For the present Draining of the Great Level of the Fens, (called Bedford Level) Lying in Norfolk, Suffolk, Cambridgeshire, Huntingtonshire, Northamptonshire, Lincolnshire, and the Isle of Ely. As it was delivered to the Honourable Corporation for the Draining of the said Great Level, the 4th of June, 1664. As Also, Several Objections answered since the Delivery of the said Designe: with Objections to the Designe now in agitation. And as for the New Works intended in this Designe, appears in the annexed Map; and the Charge of the whole Calculated* (London, 1665).

Dugdale, William, *The History of Imbanking and Drayning of Divers Fenns and Marshes, Both in Forein Parts, and in this Kingdom; And of the Improvements thereby. Extracted from Records, Manuscripts, and other Authentick Testimonies* (London, 1662).

Elstobb, William, *Observations on an Address to the Public, Dated April, 20, 1775, Superscribed Bedford Level, and Sign'd Charles Nalson Cole, Register…* (Lynn, 1776).

Fortrey, Samuel, *The History or Narrative Of the Great Level of the Fenns, Called Bedford Level, With a Large Map of the said Level, as Drained, Surveyed, & Described by Sir Jonas Moore, Knight, His late Majesties Surveyor-General of his Ordnance* (London, 1685).

Fuller, Thomas, *The History of the University of Cambridge, since the Conquest*, printed with *The Church-History of Britain, From the Birth of Jesus Christ Untill the Year MDCXLVIII* (London, 1655).

H. C., *A Discovrse Concerning the Drayning of the Fennes and Svrrovnded Grovnds in the sixe Counteys of Norfolke, Suffolke, Cambridge with the Isle of Ely, Huntington, Northampton, and Lincolne* (London, 1629).

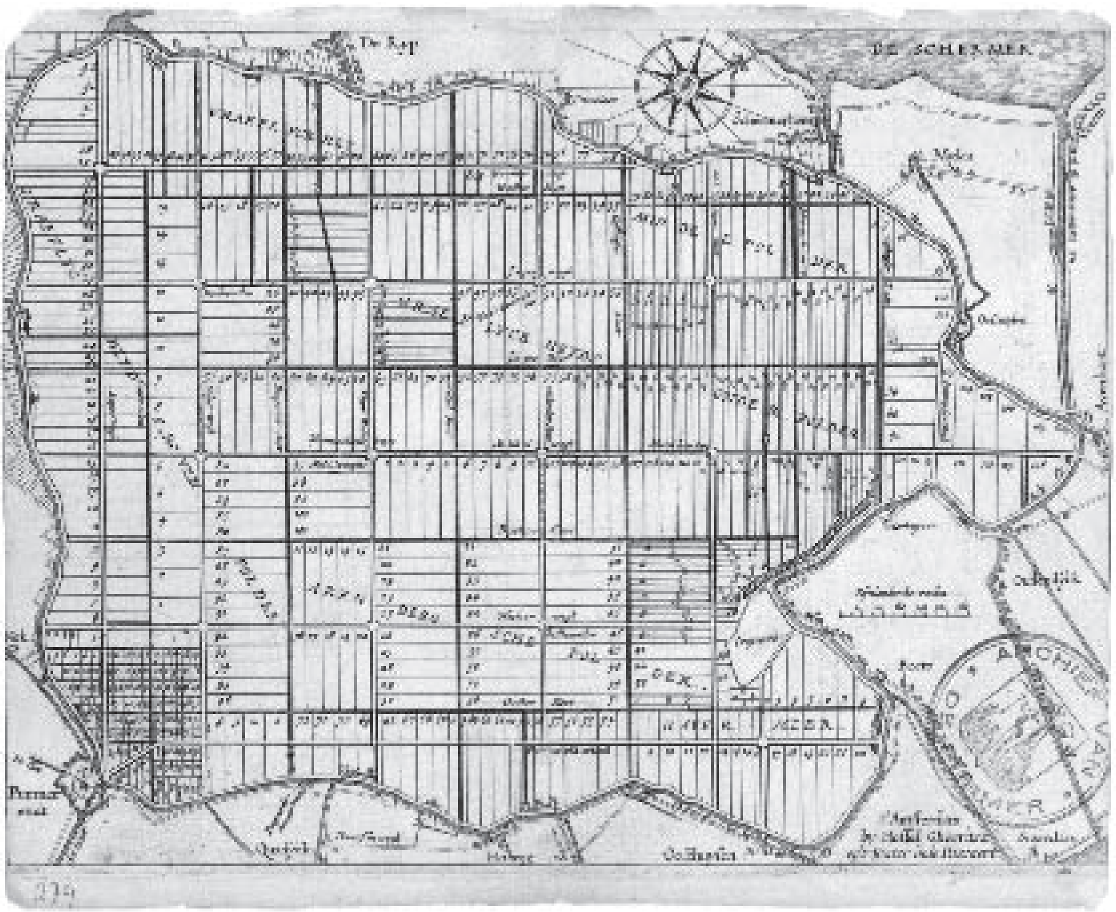
I. L., *A Discourse Concerning the Great Benefit of Drayning and imbanking, and transportation by water within the Country* (London, 1641).

Moore, Jonas, *A Mapp of y^{e} Great Levell of y^{e} Fenns extending into y^{e} Covntyes of Northam^{p}ton, Norfolk, Suffolke, Lyncolne, Cambridg & Huntington & the Isle of Ely as it is now drained, described by S^{r} Jonas Moore Survey^{r} gen^{ll}*, 3rd. ed. ([London], [c. 1706]).

Scotten, Edmund, *A Desperate and Dangerovs Designe Discovered Concerning the Fen-Countries, By A faithfull friend, who as soone as it came to his knowledge, hath taken some pains, not only to discover, but to prevent the same; By order of the Committee for the Fenns. Published for the Common-good, and in all humility presented to the High Court of Parliament. And in particular to some Noble Personages especially interessed* [sic] *and concerned therein* (London, 1642).

Sprat, Thomas, *The History of the Royal-Society of London, For the Improving of Natural Knowledge* (London, 1667).

Vermuyden, Cornelius, *A Discourse touching the Drayning the Great Fennes, Lying Within the several Covnties of Lincolne, Northampton, Hintington, Norfolke, Suffolke, Cambridge, and the Isle of Ely, as it was presented to his Majestie* (London, 1642).



Hessel Gherritsz, *Beemster*, 1612, courtesy of Waterlands Archief, Purmerend inv.nr. 279.

ILLUSTRATION 17

The Beemster Polder: conservative invention and Holland's great pleasure garden

Alette Fleischer

The Beemster Lake, seventy-one square kilometres in extent, was the biggest of a series of lakes north of Amsterdam drained in the seventeenth century for land-based development.[1] The resulting Beemster Polder was constructed between 1608 and 1612. It has since been hailed for many different reasons: as a triumph over water, a statement of Dutch power over nature, a product of technical ingenuity and organisational prowess, a site of agricultural abundance and a repository of architectural and horticultural beauty. The polder came to epitomise Dutch ideas of pristine nature, wholesome and blissful living, just as it symbolised the peace and wealth of the new Dutch Republic. It was celebrated for its pastoral richness, its pleasant country estates and beautifully designed gardens.[2] The variety of its meanings has attracted a comparable variety of historical accounts. Commentators have remarked on the architecture of the landscape and the country estates. They have lauded the Beemster as a pastoral retreat. Some historians claim that the Beemster was only built once new draining techniques had been developed. Others emphasise the role of individual practitioners such as the millwright Jan Adriaansz Leeghwater, the financier Dirck van Os or the land surveyors involved in the scheme.[3]

However, the project to build the Beemster Polder was not welcome to all, nor was it at once nor uniformly successful. The labourers whose very livelihood

[1] G.P. van de Ven, ed., *Man-made Lowlands, history of water management and land reclamation in the Netherlands* (Utrecht: Stichting Matrijs, 2004 (first published in Dutch, 1993)), p 161.

[2] See the poems by: C. Barleus, *Oostwijck* (1653), J. van den Vondel, *De Beemster* (1644) and A. Wolff, *De bedyking van de Beemster* (1773); the comments of Cosimo de' Medici in G.J. Hoogewerff, *De twee reizen van Cosimo de' Medici Prins van Toscane door de Nederlanden (1667-1669)* (Amsterdam: Johannes Müller, 1919), p. 272.

[3] For instance: Chris Streefkerk, Jan Werner and Frouke Wieringa, eds., *Perfect gemeten, landmeters in Hollands Noorderkwartier ca. 1550-1700* (Alkmaar: Stichting Uitgeverij Noord-Holland, 1994); Wouter Reh and Clemens Steenbergen, eds., *Zee van land. De droogmakerij als architectonisch experiment* (Delft: Technische Universiteit Delft, 1999); Toon Lauwen, ed., *Nederland als kunstwerk; vijf eeuwen bouwen door ingenieurs* (Rotterdam: Nai Uitgevers, 1995); J.G. de Roever, *Jan Adriaenszoon Leeghwater, het leven en werk van een zeventiende-eeuws waterbouwkundige* (Amsterdam: Wed. J. Ahrend, 1944); Marc Glaudemans, *Amsterdams Arcadia, de ontdekking van het achterland* (Nijmegen: SUN, 2000), p. 132.

depended on the watery Beemster were not compensated for their losses; they responded by breaching holes in the new drainage dyke and were countered with legal proclamations against their sabotage. Furthermore, the new polder proved initially too wet for arable farming. Most of it was only suitable for grassland, thus for keeping cattle, for milk and meat. The Beemster needed more windmills to pump water, and required ever deeper ditches and canals. Roads had to be raised and finished. Subsidence of the drying earth and maintenance of a sufficiently low water level posed yet further difficulties. It was known from previous drainage schemes that subsidence occurred, but in this case subsidence was insufficiently anticipated. Every winter, to the financial despair of stakeholders and farmers, the lowest part of the Beemster flooded anew. Many other fiscal, agricultural and engineering difficulties plagued the programme's success.[4]

Thus to interpret the construction of the Beemster polder as an obviously victorious transformation of nature into culture and a brilliantly successful application of the ingenious devices of the early modern oeconomy of water management, required considerable ingenuity itself. Due to its large scale and size, the venture demanded a different approach from that adopted towards the smaller and shallower lakes that had been drained in the sixteenth century. The drainage led to an exchange of experiences and of custom-based ideas. It provided occasions for the articulation of contemporary and classical notions of Nature, husbandry, water management, urban architecture, mathematics and garden design. This essay argues, therefore, that the creation of the Beemster gave rise to an ongoing and analogous transformation of received ideas and practices in garden aesthetics and economic techniques to fit local circumstances. For reasons that were equally social, economic and technical, the inventions that were adopted tended to be conservative, based on tradition and custom. This inventive enterprise paralleled the hermeneutic process through which the Beemster builders gave meaning to their project. Inventive ideas and practices were conservative in the sense that they emerged through the re-investigation of familiar techniques, aesthetics and ideas. 'Conservative invention' may seem an oxymoron; the apparent tension was resolved through the social networks of the Beemster project. While protagonists proved willing to adopt novel theories and techniques, these innovations had to be comprehensible and acceptable to others.

The Beemster was an artificial land that with the help of skill, invention and the arts was turned into 'Holland's great pleasure garden'.[5] Today the Beemster

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[4] J.G. de Roever, *Leeghwater*, p. 108.

[5] Jan Adriaansz. Leeghwater, *Haarlemmermeerboek* [etc], 9th edition (Amsterdam: Pieter Visser, 1724). All translations are mine, unless stated otherwise.

is often seen as a mere drainage scheme whose only merits are judged functional: farmland and dwelling space. Yet to see the Beemster as a garden as well can help explain how it was possible for the early modern Dutch willingly to risk money and resources, adapting and adopting inventions in order to understand, design, rework and husband Nature for pleasure and production.

Wild nature and controlled nature

In the seventeenth century, according to the historian Clarence Glacken, it was argued that 'men must actively interfere with brute nature … in order to maintain civilisation. Nature untouched by man is a lesser nature and the economy of nature is best where man actively superintends it. The role of man as a caretaker of nature, a viceroy, a steward of God….'.[6] Untamed Nature was associated with the chaos that overcame the Earth after the Fall and the disruption of the harmony that existed between Nature's four elements and three kingdoms. The challenge was to recover this divinely created harmony through the work of oeconomy, to remodel Nature into its prelapsarian state. But God's stewards resorted to more than scriptural precedent to cultivate their land. In this drive to tame brute Nature, they also appealed to written mythological and classical garden typology. Gardeners drew inspiration both from the biblical Garden of Eden and from the classical models of pastoral Arcadia and the Garden of the Hesperides. Increasing numbers of books on garden design and gardening appeared in the seventeenth century as the fashion spread from Italy north to the Low Countries. The merger of these ancient ideals and the application of these principles both in contemporary gardens and writings led to new typological inventions.

These classical notions had to be adapted to Dutch conditions, in light of the local environment and aesthetic sensibilities. Here seemingly abstract and apparently mundane expertise mingled. By combining knowledge of local circumstances with knowledge presented in garden books, a gardener could create a simultaneously flourishing and fashionable site. The social milieu had to provide resources for such ideas. Each horticultural enthusiast might learn from books and from colleagues in order to recreate a private paradise. Natural economy was cultivated by its stewards through experience and gardening, through theory and literary garden typology, and socially in the gardens of others. On the one hand, the garden was rooted in classical soil; on the other, it was adapted to local exigencies. This was how, in all spheres, conservative inventiveness was at work.

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6 Clarence J. Glacken, *Traces on the Rhodian Shore, nature and culture in western thought from ancient times to the end of the eighteenth century* (Berkeley: University of California Press, 1984), p. 482.

The choice of a specific garden iconography depended on the message the owner wished to convey in a horticultural language comprehensible to his peers. The garden, its content and context could be discussed, criticised or admired with these fellows. It was a means of projecting the protagonist's interest in a specialised field and simultaneously portraying knowledge and power over Nature. Gardens were also display cases for divine creativity. The ideal was to accumulate every possible specimen of animals, plants and minerals.[7] Merchants and seamen gathered, stole, hunted, purchased or concocted exotic goods for the European market, to meet the demand for curiosities and wonders of new worlds. So a garden could house sculpture, various exotic plants, topiary, herbs and vegetables, hothouses, fish ponds, fountains, grottoes filled with minerals and galleries of stuffed animals and dried plants. Everything had its place in the garden, thus thematised and controlled.

To this mixture, Dutch culture added an idiosyncratic emphasis on political identity. The Beemster, too, begot a symbolic meaning that lifted this garden to a mythological level, reflecting on the Dutch prowess to create their own country. The young Republic of the United Seven Provinces was often imagined as recreating the ancient 'Land of the Batavians,' envisioned metaphorically as the *Hortus Batavus* or 'Garden of Holland'.[8] With the founding of the Republic, this horticultural typology became a symbol of peace and prosperity. Depictions of the *Hortus Batavus* show a seated Dutch Maiden, crowned with a spire, in an enclosed garden surrounded by flowers, globes and an orange, the symbol of the ruling House of Orange. The entrance is guarded by the Lion of Holland. In 1644 the poet Joost van den Vondel compared the Beemster with this Dutch Maiden: 'Her forehead's spired crown piercing through the clouds: as communal wealth in its noblest sense creates luxury'.[9] (Ill. 18) The Beemster was thus in principle a symbol both of the *Hortus Batavus* and the Dutch Maiden, and also of the young Republic. Around the polder, a dyke enclosed and protected artificial territory and kept the Dutch safe against their great enemy, water.

First, second and third nature

It was claimed that untamed nature could be transformed into a new Edenic landscape with the help of art (*conste*). In seventeenth-century Dutch, the word

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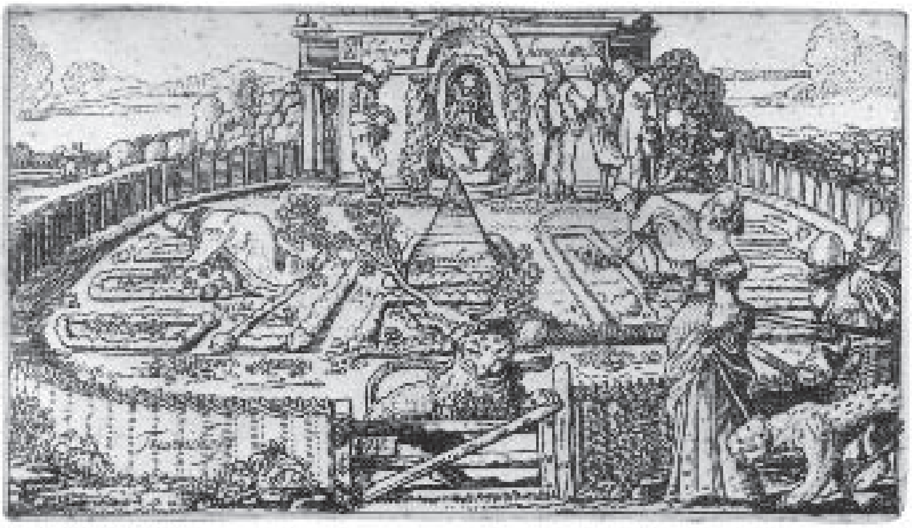
7 John Dixon Hunt, 'Curiosities to adorn cabinets and gardens,' O. Impey and A. MacGregor, eds., *The origins of museums, the cabinet of curiosities in 16th and 17th-century Europe* (Oxford: Clarendon Press, 1985), p. 201.

8 Vanessa Bezemer Sellers, *Courtly gardens in Holland 1600-1650; the House of Orange and the Hortus Batavus* (Amsterdam: Architectura & Natura Press, 2001), p. 12.

9 Joost van den Vondel, *The Beemster*, a poem for Karel Looten a landowner in the Beemster (1644). http://www.dbnl.org/tekst/vond001dewe04/vond001dewe04_0125.htm



Ill. 18. Willem Buytewech, *Allegory on the Twelve Year's Truce*, 1615, courtesy of Atlas van Stolk, Historisch Museum Rotterdam.

conste meant more than 'art,' but also labour, skill and technique.[10] This semantic scope included practicality and aesthetics in a way that the current definition of art excludes. The engineer Nicolaas de Wit, referring to the drainage of the Pontine Marshes in Italy, used this term *conste* (ca. 1630) in relation to the reworking of the swamps, that produced 'foul smells and housed many evil animals'.[11] The marshes ought to be returned to their former beauty, fertility and clean air, so that with God's consent the inhabitants could live in a sound and prosperous environment. Jan van der Groen, gardener to stadholder William of Orange, wrote along similar lines in 1669 that art could make chaotic nature orderly, elegant, pleasant and stylish. He told his readers that nature presented itself in a disorderly fashion, but when aided by the arts, experience and inventions, it could be transformed into a beautiful garden.[12] Van der Groen and De Wit used similar terms to characterise the taming of Nature. De Wit used the words *conste*, *arbeijt* (labour) and *vernuftheit* (engineering and intellect), while Van der Groen wrote of *consten* (arts), *ervaringen* (experiences) and *uitvindingen* (inventions). With human skill, invention and co-operation, landscapes and gardens could be made beautiful and fertile.

[10] *Conste* means art, artificial, or technical. *Vernuftheijt* was related to intellect, engineering, skill. *Woordenboek der Nederlandsche Taal* (Den Haag: SDU, 1993-2001).

[11] J. Korthals Altes, *Polderland in Italië; de werkzaamheden der Nederlandsche bedijkers in vroeger eeuwen en het Italiaansche polderland voorheen en thans* (Den Haag: Stockum, 1928), pp. 223-224.

[12] Jan van der Groen, *Den Nederlandtsen hovenier* (Amsterdam: 1669).

Van der Groen's important treatise *Den Nederlandtsen hovenier* (The Dutch gardener) was a compendium of earlier horticultural writers' ideas combined with his own experience as a gardener.[13] It was generally held that wild and chaotic nature could be transformed into an *alteram naturam*, a Ciceronian cultural landscape with roads, bridges and fields.[14] This was a managed nature fit for habitation and consumption, opposed to untamed 'first nature'. Within such a scheme, gardens could be considered a 'third nature', nature that was not only husbanded but also aestheticised. The propaganda of the Beemster financiers urged that this lake was an example of brute first nature that had to be cultivated to form a hybrid of second and third nature. It had to be transformed into an oeconomical environment, where profitable husbandry and beautiful gardens fed body and soul.

It was certainly possible to link these enterprises with the visions of Baconianism.[15] The English courtier and philosopher offered specific remarks on gardens in his *Essays or counsels*. Bacon stressed the importance of co-operation, since 'the People wherewith you Plant, ought to be Gardners, Ploughmen, Labourers, Smiths, Carpenters, Joyners, Fisher-men, Fowlers, with some few Apothecaries, Surgeons, Cookes, and Bakers'. And he valued advice: 'for Great Princes, that for the most Part, taking Advice with Workmen, with no Lesse Cost, set their Things together'.[16] Bacon urged that the co-ordination of knowledge, labour and skill could change nature into an artfully enhanced environment. This was just what occurred with the Beemster Lake. Garden aesthetics and commercial ideals jointly formed the basis of its outline. The Beemster was not transformed into a new nature simply by changing it into a consumer landscape. It was shaped using geometry and symmetry as its main design principle. The design of this landscape was well planned and organised by the land surveyors and members of the project's board of stakeholders. They reckoned that husbanding wild nature and creating a hybrid of second and third nature were one and the same process.

As was common in seventeenth-century architecture, the Beemster's basic design principle was the rectangle. This classical idea undergirded urban, military and garden architecture. Through the traffic of books and people,

[13] Vanessa Bezemer Sellers, *Courtly gardens*, p. 181. Van der Groen drew from French, Flemish and German sources, like J. Vredeman de Vries, *Hortorum viridariorumque formae* (1583) and D. Loris, *Le thrésor des parterres de l'univers* (1576).

[14] John Dixon Hunt, *Gardens and the picturesque, studies in the history of landscape architecture* (Cambridge: MIT Press, 1992), p. 3.

[15] The work of Francis Bacon was known in early 17th century Holland. The 'Essays' were translated in Dutch; Christiaan Huygens owned a copy of the Dutch version dated 1646.

[16] Francis Bacon, *The essayes or counsels, civill and morall* (Oxford: Clarendon Press, 1985), 'Of plantations XXXIII' and 'Of gardens XLVI'.

fascination with the ideal of regular and symmetrical forms found its way north. In the Low Countries, one of its promoters was the influential mathematician and engineer Simon Stevin, especially in his book *Vande oirdeningh der steden* (On the layout of towns) published around 1600. Appealing to ancient and contemporary precedents, Stevin also advocated straight streets, even-sided building blocks and rectangular or geometrically-ordered houses and cities.[17] Regularity and symmetry provided an antidote against chaos and disorder, and were thus considered the most desirable design principle. Such a principle was also applied to the design of gardens, display cabinets, trellises, flowerbeds and the planting of trees. It indicated order, harmony and surveillance of the owner's property, collections and goods.

An inspection of the Beemster suggests that the surveyors and financiers applied Stevin's ideas. The original lake was cut through with roads and waterways. The land surveyor Jan Pietersz Dou explained that these were laid out in a 'commendable order of parallel lines and right angles'.[18] But the overall layout was not a design principle simply copied from Stevin's book. Rather, its grid also allowed easy access by goods and people over land and water. This was a practical issue, since, for example, the *trekschuiten* (human-towed boats) demanded straight canals. These practicalities had to be taken into consideration, as surveyors like Dou were well aware. This new land needed to be accessible, consumer-friendly and aesthetic, resulting in a hybrid between the writings of Simon Stevin and the surveyors' experience.[19]

A community of people

The urban merchants and *regenten* who invested heavily in the project judged the drainage of the Beemster Lake a good fiscal prospect. On the whole, a stakeholder was looking for new, lucrative and safe ways to invest money. Until just before the mid-seventeenth century, grain prices were high due to Holland's growing population. From earlier experiences in the drainage of other smaller lakes around Amsterdam, it was known that cereals and oil seeds flourished on the rich clay that lay at lake bottoms.[20] The wealthy merchant brothers Dirck and Hendrik van Os of Amsterdam were among the first to

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17 Ed Taverne, *In 't land van belofte: in de nieue stadt; ideaal en werkelijkheid van de stadsuitleg in de Republiek 1580-1680* (Maarssen: Gary Schwartz, 1978), pp. 43-45.

18 H.C. Pouls, *De landmeter Jan Pietersz Dou en de Hollandse Cirkel* (Delft: Nederlandse Commissie voor Geodesie, 2004), p. 80.

19 On the historical relation between precedent and decisions borne of practical experience, see Katherine Rinne's essay in this volume.

20 G.P. van de Ven, *Man-made Lowlands,* p. 165; Jan A. Leeghwater, *Haarlemmermeerboek*.

raise capital.[21] These two well-educated and well-connected refugees from Antwerp were co-founders of the VOC, the Dutch East India Company. To spread the risk, the prospective Beemster was divided into parts and sold as stakes. The first sixteen stakes were issued in 1607, eventually increasing in number to around 120 stakeholders.[22] A small group of stakeholders formed a board of overseers, supervised the drainage, hired the workforce and controlled the finances. At first the board were not aware of the implications of the project. They only visited the lake after their enterprise was patented. Thenceforward the board energetically advanced the work, gathering information from farmers on means of closing gaps in waterways and on the situation and methods for dyke construction.[23] The board also had to confront the interests of those who already drew income from the Beemster Lake, such as local fishermen and the farmers who used rich lake clay as fertiliser. While many unrewarded workmen who found their economic survival in question, responded with violence and were dealt with by proclamation, the board was perfectly willing to pay financial compensation to their fellows on local village councils and cities.[24]

The people responsible for financing the drainage consisted of merchants, civil servants, lawyers and burgomasters. One was a goldsmith. All knew each other directly or indirectly.[25] This was a social group forged of mutually profitable advantage. The link between money-making and erudition gave *nouveaux riches* access to a learned establishment. This alliance offered status and access to universities, societies and influential people. Meanwhile, these wealthy tradesmen injected money into their new social circle. Friendship and marriage helped unite these two worlds, as in the marriage of the daughter of Karel Looten, a rich merchant and participant in the Beemster project, to the Leiden theology professor, Karel Heidanus.[26] The mercantile Looten family could boast not only of their connection with a Leiden professor but counted amongst their acquaintances the poet Joost van den Vondel, eulogist of the

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21 Wouter Reh and Chris Steenbergen, *Zee van land*, p. 56. After the Fall of Antwerp, the Van Os brothers moved to Amsterdam.

22 J. Bouwman, *Bedijking, opkomst en bloei van de Beemster* (Purmerend, Schuitemaker, 1857, reprint 1977). This book contains most decrees and minutes of the Board of the Beemster. p. 32.

23 G.J. Borger, 'De Beemster – ideaal of compromis,' in R.M. van Heeringen, E.H.P. Gordfunke, M. Ilsink and H. Sarfatij, eds., *Geordend landschap, 3000 jaar ruimtelijke ordening in Nederland* (Hilversum: Verloren 2004), pp. 75-102.

24 J.G. de Roever, *Leeghwater*, p. 93-94; see also Eric Ash's essay in this volume.

25 Helga Danner, *Van water tot land, van land tot water; verwikkelingen bij de indijking van de Beemster* (Wormerveer: Kunstdrukkerij Mercurius, 1987), p. 9ff.

26 Willem Otterspeer, *Groepsportret met dame I; het bolwerk van de vrijheid; de Leidse universiteit 1575-1672* (Amsterdam: Bert Bakker, 2000), pp. 76, 304-5; Johan E. Elias, *De vroedschap van Amsterdam, 1578–1795* (Haarlem: Loosjes, 1903-1905), p. 197.

Beemster. Professor Heidanus collected Roman antiques, statues and coins. His chamber of antiquities housed various cabinets filled with ethnographica, naturalia, weapons, curiosities and prints.[27] Marital unions such as this linked water flows and knowledge flows. Merchants such as Looten understood the importance of gathering knowledge of goods, shipments, plants, animals, agriculture and any other topic that helped provide for one's livelihood and maintain a certain standard of living. Amsterdam was a marketplace for the exchange of goods, stocks and shares and an important centre for information exchange. Rapid postal delivery, the rise of business newspapers and a tightly knit infrastructure assured that information, like private and business correspondence, reports and prices of shares, found their way to and from the city of Amsterdam. Collecting, distributing and processing facts were vital to maintain the network of local and foreign merchants as well as maintaining other networks. Information on subjects such as botany, simples, instruments, measures, designs, natural history and medicine became more easily available. As with the organisation of the VOC, the Beemster project entailed extensive paperwork, information regarding the lake, patents, lawsuits, minutes, charts, correspondence, decrees, general announcements flowed in and from the board's office. Collecting data, making decisions, reporting back to the other stakeholders and filing all the paperwork was in fact a mercantile invention that made Amsterdam an important information and commercial exchange.[28] This information system promoted the distribution of learning, not only in oeconomy and the prices of goods, but also in the field of natural history.

Designing the Beemster

Since the board financed the project by selling stakes, it was crucial to know the extent of the new territory and how to divide it into evenly sized plots of land. This put pressure on the land surveyors to produce detailed charts as soon as possible. Mapping was the first step in transforming the Beemster's nature. The shape and size of the lake were manipulated by the land surveyors, engineers and financiers. On 21 May 1607 a decree was drawn up by the major project's financiers stating that a commission consisting of four financiers was to support the land surveyor. The decree instructed the surveyor to consider a ring dyke around the lake that was to be placed on the older firm land, incor-

[27] Ellinoor Bergvelt and Renée Kistemaker, eds., *De wereld binnen handbereik, Nederlandse kunst- en rariteitenverzamelingen, 1585-1735* (Zwolle: Waanders, 1992), p. 80.

[28] Woodruff D. Smith, 'The function of commercial centers in the modernization of European capitalism: Amsterdam as an information exchange in the seventeenth century,' *The journal of economic history* 44 (1984): 985-1005.

porating existing water protection systems. This was a contrast with prior dyke systems, in which the dyke would usually be built in the lake, a few meters from the shore, so that there was a natural water reservoir between the dyke and the shore. Furthermore the decree said that the *trekvaarten* (waterways for towed barges) should be easily accessible and straight, that the surveyor should make suggestions for location of the windmills and for the choice of ditches and waterways to be closed and that he should measure the width and length of the lake.[29]

In 1608, after the death of his predecessor, Lucas Sinck was appointed chief surveyor. As surveyor to the city of Amsterdam he might have met his fellow townsman Dirck van Os.[30] A team of at least five surveyors, all of whom were appointed to the province of Holland, worked on this project. Gerrit Langedijk and Augustijn Bas came from Alkmaar, Reyer Cornelisz from Warmenhuizen and Jan Pietersz Dou from Leiden.[31] In January 1611 the nearly empty lake froze solid. The five land surveyors and their assistants measured the lake on the ice using measuring chains to produce a so-called *perfecte caerte*, the 'perfect' map.[32] This chart provided the basis for the first designs of the projected Beemster Polder. Both in 1611 and in 1612 Sinck and his colleagues produced maps with indications of roads, squares, canals, waterways and the positioning of the windmills.[33] (Ill. 17) They positioned the dyke in such a way that it created the shortest shore line. The ring canal behind the dyke was to be more or less straight with as few bends and turns as possible, so that it would be suitable for the towed barges. These considerations, optimising the use of the terrain, made the shape of the Beemster relatively rectangular.

The design, with its uniform roads and waterways, differed greatly from the infrastructure of the older land. With the Board's agreement, the surveyors chose not to connect the Beemster communication system to the existing roads and gave priority to infrastructure within the Beemster. One significant concession was made however; the road connecting the neighbouring town of Purmerend with the Beemster was laid out straight from the main Protestant church into the former lake. This guided the Beemster churchgoers living nearest to the city directly toward the house of God. The Beemster's shape and geometrical pattern gave the polder a design that contrasted clearly with

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[29] J. Bouwman, *Bedijking*, p. 44-45

[30] *Ibid.*, p. 110-112, meeting of 29 March 1610.

[31] A.J. Kölker, G.H. Keunen and D. de Vries, eds., *De Beemster* (Alphen aan de Rijn: Canaletto, 1985), with reprints of most of the Beemster maps.

[32] Erik de Jong, C. Steenbergen and P. de Zeeuw, 'De Beemster. Een arena van natuur, kunst en Techniek,' Toon Lauwen, ed., *Nederland als kunstwerk*, p. 157. This map is lost.

[33] *Ibid.*, p 158-159.

the surrounding landscape. Its symmetry and regularity afforded an optimal use of space and easy access within the Beemster.

Inventions

The Beemster drainage project developed in company with the technologies used to pursue it. Technical inventions emerged in this context through the reinvestigation of known and working models. They appeared through the adaptation of existing techniques, objects, ideas and the combination of functions previously embodied in several different instruments. Two examples of such conservative inventions are discussed here: the windmill and milling techniques used for drainage and the introduction of a new surveying instrument.

The Board did not begin with a preconceived notion of which windmill design to choose. Rather mill designers were invited to present their inventions. Though the financiers knew very little about how windmills operated their voice was decisive, since they were funding the project. One condition was clear: a windmill had to be cost-efficient. The Board wanted to work with a minimum number of mills to pump the maximum amount of water in the shortest time. On 10 November 1607 seven mill designers presented their propositions. Each millwright tried to convince the Board that their invention was the best, surest, cheapest or most powerful. Despite claims that a certain invention had worked in Venice or that a certain pump could raise water to a higher level than any known mill, the board decided it was too risky to invest in new types of mills or pumping systems and that testing these models would delay the drainage. The adapted oil mill proposed by Jan Adriaansz Leeghwater was considered, as was the proposal made by Pieter Pieters and Pieter Claasz. These two men suggested using the familiar eight-sided windmill with movable top but with 'certain new additions'.[34]

Two small prototypes were thus built and investigated by three board members with the aid of mill-masters Jacob Meusz from The Hague and Pieter Jansz from Hoorn. Building models to prove mastery of skill was rather usual among the guilds. A small-scale model was especially required for expensive commissions.[35] The prototype by Claasz and Pietersz proved workable. They were contracted to build ten new windmills and to reuse six good strong older mills. This was common practice since mills were expensive. It involved disassembling a wooden mill, then adapting and rebuilding it where it was needed.[36]

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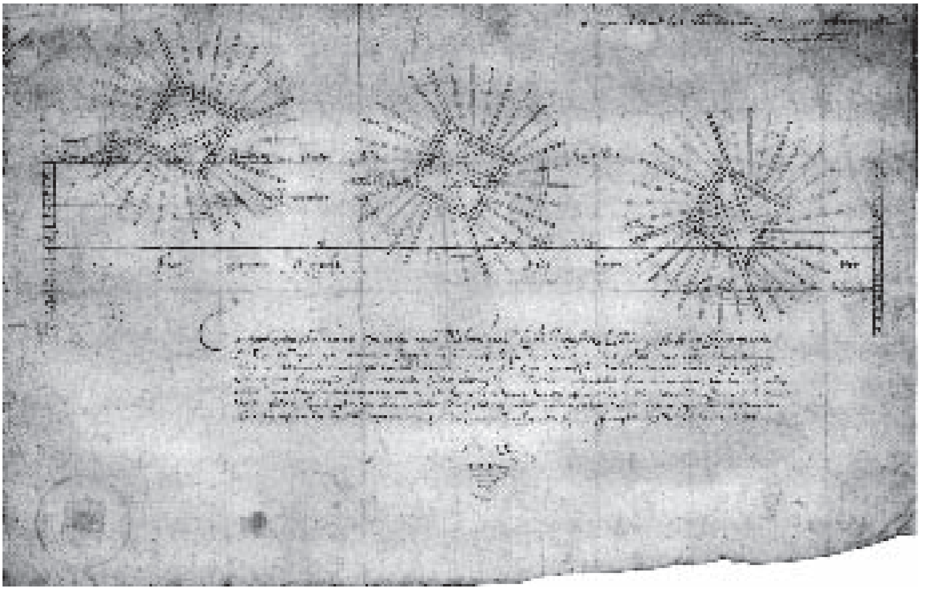
[34] J. Bouwman, *Bedijking*, p. 58-59.
[35] See for the problems with scale models, see Lissa Roberts' and Simon Schaffer's essays in this volume.
[36] J. Bouwman, *Bedijking*, p. 59-60.



Ill. 19. Jan A. Leeghwater, *Three stage milling*, 1633, courtesy of Provinciale Atlas Noord-Holland, nr. 205.

The millwrights advised building all the available mills on the same level. After the water level had sufficiently receded, the positions of the mills would be changed and the water pumped up in two stages, using a water basin between the lower and higher mill. This two-stage milling technique had been patented twenty years earlier by Simon Stevin, but the patent had rather conveniently lapsed before the drainage. It is quite possible that these millwrights were aware of the expiry of Stevin's patent. One part of the lake proved too deep for this two-stage pumping method.[37] A third stage had to be added, placing three mills in a row with two water basins between them. (Ill. 19) This meant an increase in the number of windmills to a total of at least forty-three.[38] Although the millwrights invented three-stage milling, their idea could also have been copied from Stevin's expired patent. At best, their suggestions were an adaptation of a known technological principle already proved workable by Stevin and judged reliable.

37 Erik de Jong et al, 'De Beemster'. The idea of placing mills in rows of two came from the mathematician and engineer Simon Stevin.

38 The drainage started with sixteen mills, but by 1608 there were twenty-one mills, in 1609 twenty-six and in 1612 the total was forty-three mills.

The mill technologies used in the Beemster were produced by skilled craftspeople who tried to convince the Board that their invention was cost-efficient and workable. They probably learnt their craft from a master and from working in the province of Holland, elsewhere in the Netherlands and even in Italy. Ignorant of milling, the Board resorted to hiring two advisory mill-masters when the models were shown. Their choice was eventually made on the basis of expected reliability and cost-efficiency. It has been argued persuasively that such devices were then judged on the basis of saving cost rather than labour, since to cut back on work often generated labour unrest.[39]

Another invention that emerged during the project was the introduction of a new surveying instrument by the land surveyor Jan Pietersz Dou of Leiden. In several respects, Dou's career reflected the principles of conservative invention. To become a surveyor one could learn the skill in the field from masters, but after 1600 it was also possible to attend Leiden's newly established engineering school and study *Duytsche Mathematicque*.[40] This school, linked to Leiden University, taught the techniques of engineering, land surveying, triangulation, geometry and mathematics in Dutch. Dou realised that books in Dutch on these topics were needed. With the surveyor Johan Sems of Friesland he published books on land surveying, *Van het gebruyck der geometrijsche instrumenten* (On the use of geometrical instruments) and *Practijck des landmetens* (Praxis of land surveying). These books became standard reading material for surveyors in training. He was also the first to translate the first six books of Euclid in 1605 or 1606 from French and German into the vernacular.[41] Dou showed that he combined traditional knowledge, such as Euclid's classical geometry, with direct field experience, practical novelty with classical tradition.

For the Beemster project, Dou was assigned to make depth measurements, work on the ring dyke, acquire the land on which the dyke was to be built and plan and plot the apparently interminable roads and canals in the polder.[42] While on the job, he introduced a mathematical instrument he had developed to answer his dissatisfaction with existing land surveying instruments. Dou made an instrument that served only the purpose of surveying and would

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39 S.R. Epstein, 'Craft guilds, apprenticeship and technological change in preindustrial Europe,' *The journal of economic history* 58 (1998): 684-713.

40 P.J. van Winter, 'Hoger beroepsonderwijs avant-la-lettre. Bemoeiingen met de vorming van landmeters en ingenieurs bij de Nederlandse universiteiten van de 17e en 18e eeuw,' *Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, afd. Letterkunde* (Amsterdam/Oxford/New York: Noord-Hollandsche Uitgevers Maatschappij, 1988), pp. 5-148 for further reading.

41 H.C. Pouls, *De landmeter*, p. 21; *De ses eerse boucken Euclidis. Van de beginselen ende fondamenten der Geometrie* [etc].

42 *Ibid.*, p. 22.

produce fewer errors.It consisted of a brass circle encasing a cross with a compass at its centre. On the circle were four fixed sights and two moveable sights with small openings. The whole instrument could be fixed on a pole and combined the qualities of several instruments such as the astrolabe and the quadrant. An added virtue was that it could be used for depth measures and double as a surveyor's cross. This new instrument made calculations easier, since Dou also added a goniometric division.[43] Dou demonstrated the device in the Beemster, where his colleagues took great interest in his equipment. To inform other surveyors of his invention he published a treatise on this instrument in 1612, *Tractaet vant maken ende gebruycken eens nieu gheordonneerden mathematischen instrument* (Treatise on making and using a newly ordained mathematical instrument), what explained how to make and use this new device.[44] The so-called Dutch circle or Dou's circle was a great success and was widely used in the Netherlands until the late eighteenth century.[45] Dou's invention also led to a more efficient work method. Residing in Leiden, his erudition and involvement with the new engineering school might well have helped him develop his instrument. Yet Dou devised this apparatus because of his immediate fieldwork. It was not the result of a theory that had to be tested and shown in a university theatre. Dou's Circle was presented in the field to fellow land surveyors as a piece of effective equipment that became thenceforth indispensable to any serious surveyor.

The Beemster drainage did not depend on pre-existence of these technologies. Rather, they were produced while working in the Beemster as hybrid results of direct experience and received tradition. In confronting novel predicaments, inventions such as three-stage milling and Dou's Circle were designed *in situ* to overcome costly and time-consuming obstacles. These inventions could not have been conceived other than by the people who got their feet stuck in the Beemster mud.

The four elements and Nature's 'true nature'

It is important to complement this technological account with one that stresses how the very notion of nature itself was at stake in projects like the Beemster drainage. Religious cosmology helped shape such projects as surely as did material and economic interests. Early modern practitioners viewed nature as the work of God. They sought to understand and profit from it

[43] *Ibid.*, p. 84.
[44] Ed Taverne, *In 't land van belofte*, p. 80.
[45] In the 19th century it was named the *Hollandse cirkel* (Dutch circle), but Dou just called it a mathematical instrument.

accordingly. They wanted to apprehend and recover nature's true nature, the lost prelapsarian world, which led to the creative re-construction of this Edenic garden on a grand scale. But controlling nature and simultaneously controlling the nature of its four elements was a challenge. Using the four classical elements to depict or describe a landscape, garden or site was very common in the seventeenth century. The popularity of Ovid's *Metamorphoses* was an indispensable resource. In 1586 the philosopher Justus Lipsius published his *Laus ruris*, praising the four elements for bringing profit and strength: one could feel the four elements so much better in the country than in the city. Lipsius held that in pastoral climes the sun shone brighter, the air was cleaner, clearer and extended further, the water was purer and the earth could show its true form.[46] In his *Traité du jardinage, selon les raisons de la nature et de l'art* (1638) the French royal gardener Jacques Boyceau invoked the need to the four elements in working the land for agriculture and gardening.[47]

The poet Vondel, whose evocation of the Beemster was peculiarly eloquent on questions of elemental cosmology and metaphoric figuration of the polder's meanings, also turned to the four elements in his descriptions of nature, drawing explicitly on Ovid for inspiration.[48] In his portrayal of the Beemster, Vondel used his vision of the elements to describe their manipulation:

The wind-king, to please the grieving Dutch Maiden,
After all the damages he had caused by storm upon storm,
Moved the mills' wings which, ceaselessly turning, milled
The Beemster into pasture, draining the lake into the sea.
The sun, surprised, saw salty clay, still wet from the waves,
And dried it and gave it an imposing green bodice
Lusciously embroidered with flowers, foliage, fruit and airs
And decorating her hair, sprinkling it with rich scents.[49]

The four elements were tamed and made to assist in the polder's construction. Windmills harnessed air to transmute the watery Beemster into earth, which was subsequently dried by the heat of the sun. In order to avoid chaos in

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[46] Christiane Lauterbach, *Gärten der Musen und Grazien, Mensch und Natur im niederländischen Humanistengarten 1522-1655* (Berlin/München: Deutscher Kunstverlag, 2004), pp. 90-91.
[47] Jacques Boyceau, *Traité du jardinage, selon les raisons de la nature et de l'art* (Paris: 1638; reprint 1997), pp. 1 and 4.
[48] Arie Jan Gelderblom, *Mannen en maagden in Hollands tuin; interpretatieve studies van Nederlandse letterkunde 1575-1781* (Utrecht: Rijksuniversiteit Utrecht, 1991), pp. 63-77. 'Fire gets its place in the sky, in the shape of the stars, under the sky is air, the place where birds fly, then there is earth with on it the animals, and around the earth is water, filled with fish'.
[49] Joost van den Vondel, *Beemster*.

nature, Vondel argued, each element needed to be in balance with the others. To achieve this balance, the elements had to be understood.

The cosmology of the four elements provided rich resources for making and making sense of the Beemster project and cognate horticultural enterprises. Earth was reorganised, moved and reshaped, dug out and built up to form dykes, fields, straight ditches and lanes. The territory was surveyed, plotted, exposed from the bottom of the lake and designed into measured plots of land. The surveyor's representation indicated the general layout, giving information on the condition of the terrain, the drainage system and the quality of the different soils. These variables led to a different practice of husbandry within the Beemster. On a smaller scale, the same happened in the preparation and building of the polder's large estates and their formal gardens. There the horticultural amateur worked with the architect, the land surveyor and the gardener to arrange and design a house, outbuildings, gardens and waterworks. The typical estate consisted of a house placed in the centre of symmetrically-designed garden where everything had its place, function and meaning. A central axis divided the garden into two equal halves. Both sides had intricately designed flower beds, clipped box trees and greens. Straight paths lined with trees cut through the garden, leading toward features like rectangular pools, star-shaped forests, statues, fountains and the kitchen gardens and orchards.

Water could be an ally, providing fish and paths for transport, but it was also a severe enemy of the Low Countries. Once constrained by dykes the role of water changed. The lake was pumped up by the windmills and emptied into the circular canal around the Beemster. Excess water had to be disposed of via the canals, but the water that was needed had to be collected and stored in cisterns for irrigation, the fishponds or to maintain the required water-level. Water was also used for playful objects such as hydraulically operated automata, fountains and as a decorative element in shell-covered grottoes.

Air also had a double role in the garden, in the form of wind and the sky. It posed a threat as westerly winds and storms could harm the garden and the house which therefore needed to be protected. To do so, garden owners planted double rows of trees around their houses and grounds. The trees broke the wind and sheltered the garden's more delicate plants and flowers. On the other hand, wind was a resource, used to set windmills in motion, thus helping to drain the Beemster. Wind also distributed the scent of flowers through the air. The sky could be manipulated as well. Bushy trees could disclose the sky to the wanderer and give protection against the sun or rain. And as a subtle garden feature, the sky could be reflected in so-called mirror pools. With these ingenious techniques, the clouds and the sun were seen simultaneously above and on the level of the ground.

The last element, fire, was essential when it came to keeping and growing precious and delicate exotic plants and seeds. In hothouses, stoves and orangeries the warmth of fire was distributed in such a fashion that each type of plant got the right amount of heat.[50] The warmth of the sun was also put to good use. In orchards, south-facing serpentine walls provided tender fruit trees with extra warmth and cover against the wind. Special glass lanterns and melon boxes were introduced to grow Mediterranean fruits and flowers. With sunlight and the warmth generated from manure, enough heat could be collected to germinate seeds. Gardeners busied themselves with manipulating the seasons, creating a seemingly endless Edenic spring and this way extended the growth and supply of fresh vegetables, fruits and flowers.

Charting the Beemster Lake and the surrounding environment made it possible to understand the lake's nature and change it. Measurement and draughtsmanship demanded more than the mere gaze directed at the landscape; it needed to be examined. The surveyors needed to scrutinise the lake, its terrain, the quality of its shore, to measure its depth and its overall size and shape. Drawing and charting became what has been called a 'process of re-creating with our own hand what lies before our eyes' through which one acquired an 'understanding of its constituent parts'.[51] But what were these constituent parts? The Beemster's transformation involved more than dividing the terrain into quantitatively defined units. Surveyors' drawings were also the first step in constructing a controlled nature in which the four elements that composed it were brought into productive harmony. Indeed, contemporary wisdom had it that the project actually restored the primal elemental balance lost in the Fall.

The Beemster's nature was thus changed to fit the needs and wishes of the community. With the help of artifice, skill, ingenuity and experience, nature's four elements were changed and reorganised. The elements needed to be reworked and controlled, and by doing so, gave rise to inventions and a new understanding of nature. The Beemster was to be changed from an untidy, chaotic, and dangerous lake into a mythical, prosperous and peaceful *Hortus Batavus*. To find nature's 'true nature', to understand the natural elements of water, earth, fire and air and transform them, was an important aim in the seventeenth century. This was the case in France with the building of the Canal du Midi and in England with the drainage of the Fens.[52] There too a seemingly

[50] Chandra Mukerji, 'Storehouses to stoves: built environments and the early Dutch plant trade,' a paper presented at the symposium 'Dutch Culture in the Golden Age', (University of Pennsylvania: Philadelphia, April 1999).
[51] Alain de Botton, *The art of travel* (London: Penguin, 2002), p. 222. He refers to the 19th century painter John Ruskin but it is also approriate for the seventeenth century artist.
[52] See Chandra Mukerji's and Eric Ash's essays in this volume.

inaccessible or inhabitable environment was reshaped through a transformative understanding of its nature into what was considered an improved landscape, where nature's four elements were controlled and harmonised.

The Beemster: an invention rooted in fertile soil

Like other seventeenth-century landscapes and gardens, the Beemster was reworked in the image of a profitable and pleasurable environment where nature's elements were manipulated to co-exist in harmony. The investigation and manipulation of the four elements gave rise to inventions of a conservative nature. These inventions were then distributed, adapted, changed and re-used in other forms and ways. By taking lessons from the Book of Nature, combining this with Scripture and the arts, projectors envisaged a well-structured and ordered garden where everything and everyone would know their place. Here was a balanced and harmonic environment that was supposed to recall a pristine past. The Beemster was not only an Edenic landscape, with references to the Judaeo-Christian tradition, but also referred to a classical past. Eden was a model for synthesis of all the natural and mineral elements lost after the Fall. To learn from God's work was for the garden enthusiast a learned pleasure. Invocation of the classical pre-urban Arcadia put emphasis on the pastoral also to be found in the Beemster.[53] Farming and husbandry provided food for its inhabitants, but in the Beemster garden there was also the element of profit and orderliness. The *Hortus Batavus* was the typical Dutch garden model. The Dutch Maiden ruled the garden, symbolising the wealth of the Republic and its overseas possessions. Protected by the Lion at the gate, the Dutch were envisioned as labouring in her garden, for profit, for study and for pleasure.

In his poem, Vondel referred not only to the *Hortus Batavus* and the Dutch Maiden, but also to the Greek goddess Aphrodite. He concluded his poem with the words: 'I know, from the foam of the sea this Goddess was born'.[54] When he compared the drainage of the Beemster to Aphrodite's birth, he gave expression to the common notion that man had power over nature. This land was born from the foam of the sea and, like Aphrodite, was given the same quality, that of fertility. The rhetoric devoted to the Beemster involved praise of its lush gardens, abundant crop and livestock. Hence emerged the comparison with the fertile goddess. Vondel's comparison also embodied the view that the goddess of the Beemster was not created by another deity but by the Dutch people themselves. They acted like gods when they transmuted water

[53] Marc Glaudemans, *Amsterdams Arcadia*, p. 142.
[54] Joost van den Vondel, *Beemster*.

into land. The Dutch were masters over their hard-won Republic and were their own stewards over their land, answerable only to God – the king of kings. The proverb that 'God created Earth, but the Dutch created their own country' seemed apt. (Re-)creating a pristine and pastoral landscape was not achieved by one agent but by a community of people. Yet these seventeenth-century makers knew that God had to be thanked and praised for their successes. Without His help, they held, no-one could change nature and learn about His work. According to the doctrines of Dutch Protestantism, knowledge about God was not limited to theologians, preachers or learned men, but achievable by every citizen. All members of the community could participate in this goal and working together on this project was open to everyone.[55]

Like other ways of reworking the landscape, gardening was a collective and inventive venture. This co-operation led to the transformation of their environment by the Dutch on their fellow-citizens' behalf. The Beemster was not the simple culmination of prior inventions and knowledge already achieved. It was, rather, the result of combining received notions with novel experiences in the field, 'certain new additions' – as one of the Beemster millwrights put it. These conservative inventions, whether technical, theoretical or aesthetic, had to meet social and economical demands. The same set of demands prevented radical innovation.

Daily life in and with the Beemster

Yet, however impressive the rhetorical and technical resources invested in its construction, the perfection of the Beemster needed much further work, in drainage, excavation, subsidence and agricultural overhaul, notably the transformation of planned arable into pastoral farming. Thus before the new polder could fully present itself as Holland's greatest pleasure garden and live up to the metaphor of a Dutch Maiden or Aphrodite in an embroidered green bodice, many practitioners had to work hard to change the Beemster's reality and its appearance. The workforce had to plough through the wet clay, measuring the canals, roads and plots, digging canals and ditches, raising the roads and staking out the plots of land. Maintaining the ring dyke was a constant problem. This process continued well into the 1630s, when the subsidence came to a slow halt. Milling the land sufficiently dry remained a constant battle until 1632, when a few crucial mills were repositioned and five new mills were added, so that the whole of the Beemster was in fact drained with not a

[55] Harold Cook, 'The new philosophy in the Low Countries,' R. Porter and M. Teich, eds., *The Renaissance in national context* (Cambridge: Cambridge University Press, 1992), pp. 115-149, see p. 137.

three-stage but a four-stage milling technique.[56] In a resolution of 1 January 1615 the millers were instructed to read their instructions more closely and to act according the ordinance. If they failed to achieve the agreed water level they were either fined or subjected to corporeal punishment.[57] Another project that took several decades to complete was the planting of trees along side the roads. In the 1612 *kavelcondities* (lot terms), article 31 stipulated that all roads should be planted with 'alder, willow and other trees'. The minutes of a meeting held in April 1615 reveal that tree-planting was postponed until the roads were firm. In 1618 all stakeholders were granted the right to plant, at their own expense and maintenance, trees on the roads and dykes bordering their land, but they were allowed to use the wood for profit. In 1682, however, all roadside trees were replaced by the Dutch elms that thrived there until the beginning of the nineteenth century.[58]

The first proper harvest of grain, barley, cole seed and oat that was sown in the spring and early summer of 1612 turned out rather well. Cole seed flourished especially well on the wet clay. But farming remained difficult due to lack of farmers and farmhands, storage and the swampy state of land and roads. People, horses and carts often got stuck knee-deep in the mud. Some of the landowners decided to grow grass and keep cattle, a profitable decision. The Beemster became ever more a green pasture and its main export goods dairy products and meat.[59] This, in fact, proved to be very profitable since the growing Dutch population could afford to buy meat and dairy products. As cereals were imported cheaply from Danzig and the Baltic region, Dutch farmers changed to more profitable goods like hemp, flax, vegetables, and livestock. The economical demand persuaded the farmers to adjust their produce and follow the market.[60]

Landowners' welfare was stimulated by the fact that they received a tax exemption for the first years. The Board explained to the States of Holland that they had to invest so much extra money in maintenance that they did not make any profit at all and therefore should be exempt from tax on consumptive goods and excise on cows and horses. This was granted until 1621.[61] As the Beemster's earth became more settled, landowners and tenants were able to profit from the land. Some of the higher areas were fit for agriculture. In the

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[56] J. Bouwman, *Bedijking*; J.G. Borger *Geordend landschap*, p. 94.

[57] Archive Beemster Polder, book 3 p. 41, resolutions. Waterlandsarchief Purmerend.

[58] On the planting of trees, see J. Bouwman, *Bedijking*, pp. 134, 157, 163, 223; for the complete list of articles of the statements, see pp. 286-299.

[59] *Ibid.*, pp. 141-13, 145-6, 175.

[60] Jan de Vries and Ad van der Woude, *Nederland 1500-1815, de eerste ronde van moderne economische groei* (Amsterdam: Balans, 2005), p. 241.

[61] J.G. de Roever, *Leeghwater*, p. 112-113.

lower, wetter areas farmers were able to keep cattle. The Beemster inhabitants started to build their houses, farms, country estates. In the centre, around the planned church square, a village appeared, topped off with a school and church. By the time the Grand Duke Cosimo de' Medici set foot in the Beemster in 1668, it had indeed become a goddess born from the foam of the sea.[62] The achievement was hard and lengthy. But the representation of the polder as an Edenic recreation pre-dated anything like its realisation. This helps show how the ideological work of horticultural myth-making and conservative precedent played a remarkable role in the natural and social oeconomies of early modern Dutch culture.

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Primary sources

Bacon, Francis, *De proef-stucken* (Leiden: Willem Christiaens van der Boxe, 1646).

Bacon, Francis, *The essayes or counsels, civill and morall* (Oxford: Clarendon Press, 1985).

Barlaeus, C., *Oostwijck* (1653), http://www.let.leidenuniv.nl/dutch/latijn/BarlaeusNederlands.html.

Blaeu, J., *Grooten atlas, oft werelt-beschrijving in welcke 't aertryck, de zee, en hemel, wordt vertoond en beschreven* (Amsterdam: J. Blaeu, 1646-1665).

Bouwman, J., *Bedijking, opkomst en bloei van de Beemster* (Purmerend: Schuitemaker, 1857, reprinted in 1977).

Boyceau, Jacques, *Traité du Jardinage selon les Raisons de la Nature et de l'Art* (Paris: 1638, reprinted Nördlingen: Verlag Dr. Alfons Uhl, 1997).

By den dijckgraeff ende hooghe heemraden van de selve Beemster te diversche tijden ghemaeckt/by den hooft ingelanden des selfs in hare generale vergaderingen gheresumeert/ghearresteert en ter ghewoonlijcke plaetsen ghedaen afficheren ende publiceren (Amsterdam: Ewout Cornelisz. Muller, 1616).

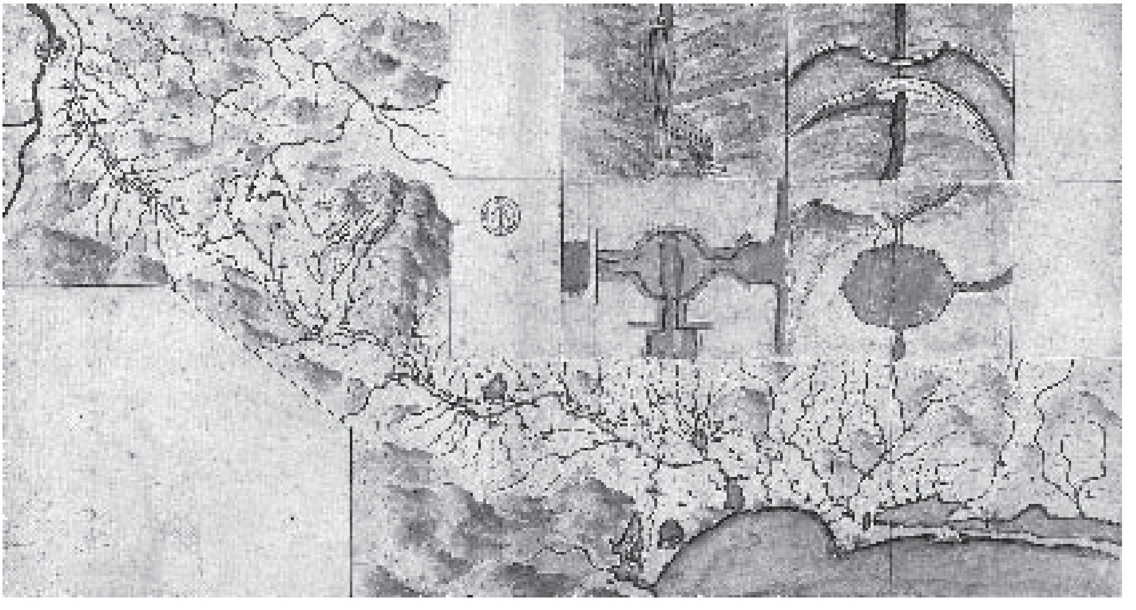
Dou, Jan Pietersz and Johan Sems, *Practijck des landmetens* (Leiden: Jan Bouwensz, 1600).

Dou, Jan Pietersz and Johan Sems, *Van het gebruyck der geometrijsche instrumenten* (Leiden: Jan Bouwensz, 1600).

Dou, Jan Pietersz, *De ses eerste boucken Euclidis, van de beginselen ende fondamenten der Geometri* (Leiden: Ian Bouwensz, 1606).

[62] G.J. Hoogewerff, *De twee reizen van Cosimo de' Medici*, p. 272.

Dou, Jan Pietersz, *Tractaet vant maken ende gebruycken eens nieu gheordonneerden mathematischen instrument* (Leiden: Jan Bouwensz, 1612).
Extract uit het octroy van de Beemster met de cavel-conditien, en de Kaerte van dien. Als mede 't Register van de participanten (Purmerend: Pieter Baars, 1696).
Groen, Jan van der, *Den Nederlandtsen hovenier* (Amsterdam: 1669).
Leeghwater, Jan Adriaansz., *Een kleyne chronyke ende voorbereidinge van de afkomste ende vergroten van de dorpen van Graft en de Ryp ende van meer verscheiden notabele oude stukken en geschiedenissen* (Amsterdam: Pieter Visser, 1714).
Leeghwater, Jan Adriaansz., *Haarlemmer-meer-boek, of beschryving, hoe men de Haarlemmer en Leytse-meer bedyken en droogmaken zal: als ook van dieptens, gronden en nuttigheid der zelver…* (Amsterdam: Pieter Visser, 9e edition, 1724).
Post, Pieter J., *Les Ouvrages d'architecture de Pierre Post, Architecte de leurs altesses les Princes d'Orange* (Leiden: Pierre van der Aa, 1715).
Resolutions, Archive Beemster Polder, book 3, Waterlandsarchief Purmerend.
Stevin, Simon, *Castrametatio, dat is Legermeting*, (Rotterdam: Jan van Waeberghe, 1617).
Stevin, Simon, *Materiae Politicae. Burgherlicke Stoffen. Vervanghende Ghedachtenissen der Oeffeninghen des Doorluchtichsten Prince Maurits van Orangie, &c. Gouverneur, opperste velt-heer, admirael-generael van de verenichde nederlanden, &c. Beschreven deur Simon Stevin van Brugge, superintendant van zijne finace, quartiermeester generael van 't leger, &c. En uyt zijn naegelate hantschriften by een gestelt door sijn soon Hendrick Stevin, heere van Alphen, van Schrevelsrecht, &c.* (Leiden: Adryaen Rosenboom, s.d.).
Stevin, Simon, *Wisconstich filosofisch bedryf…* (Leiden: Philips de Croy, 1667).
Vondel, Joost van den, *De Beemster* (1644), www.dbnl.org/tekst/vond001dewe04/.
Wolff, A., *De bedyking van de Beemster, in dichtmaet uitgesproken, op Beemsterdankdag door Adrianus Wolff, predikant in de Beemster* (Hoorn: Tjallingius, 1773, second edition).



The Canal du Midi with selected engineering details (after 1680), courtesy of Archives centrales de la Marine.

Demonstration and verification in engineering: ascertaining truth and telling fictions along the Canal du Midi

Chandra Mukerji

> *It is fair to say that the author of this proposal is full of zeal for the public good, but he apparently does not know anything ....*
> *The arguments presented here without verification are bad ones, because they lack the most important basis, that is, telling the truth.*
>
> *Avis a messieurs les Capitouls de la Ville de Tolose*[1]

In much the way natural philosophers used experiments as a focus of disputes in the seventeenth and eighteenth centuries, entrepreneurs and political elites used demonstrations, models and verifications to assess engineering projects. In both cases, the purpose was similar: to debate and ascertain truths about the natural world. In France during the seventeenth century, engineering projects on a grand scale were like scientific spectacles –great public sites for displaying knowledge.[2] They made visible tacit knowledge of natural phenomena as well as formal learning of material possibilities. Oeconomy, or redesigning nature to perfect it, was meant to be a test of human intelligence. So, it made sense to argue the virtues of grand technological experiments on intellectual grounds.

Opponents demanded evidence of feasibility and efficacy. Whatever their personal or political interests, they attacked empirical assertions and expertise. The strategy was often potent. Grand schemes pushed the limits of technical skill. And the bulk of entrepreneurs engaged in engineering projects were neither gentlemen nor natural philosophers. They were socially and scientifically

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[1] *Avis a messieurs les Capitouls de la ville de Tolose et Reponse a cat Avis, article par article par Iean de Nivelle, Ancien Capitaine Chasseauant, du Canal dans l'Ateleir de. Mr. Sagadenes,*1667. Archives de Canal du Midi (ACM) 01-16.

[2] For a discussion of scientific spectacle, see Jim Bennett's essay in this volume. And for the way the authority of the ancients was quoted in these projects, see Katherine Rinne's essay in this volume. The differences among the sciences as epistemic cultures seems to have been as important as any distinction drawn between science and engineering as epistemic cultures. See Karin Knorr-Cetina *Epistemic cultures* (Cambridge, Mass.: Harvard University Press, 1999).

problematic sources of truth. These vulnerabilities made models, measurements and assessments central to engineering practice. Successful demonstrations or measures could establish trust in entrepreneurs or their schemes. Failed measures and models also provided fuel for opponents. [3]

Military engineering projects were harder to oppose than civil ones, but were attacked and defended on similar grounds. Military engineers were more likely drawn from the nobility than civil engineers, and had greater authority with local governments. But they also depended on mock-ups, demonstrations and verifications. Engineering a new site – whether a fortress or harbour – was always an experiment and contested. Tests of efficacy were important tools for reducing the risks of failure and managing the conflicts that put into question matters of fact. [4]

In France from the turn of the 17th century, engineering became a more common tool of power. Fortresses, roads, bridges, canals and ports were built in surprising number. From the period of Henri IV, good government was equated with proper stewardship of the natural world. Contests over political power increased as capitalist trade transferred power to merchants. New infrastructure was created to serve commerce and expand the tillable land. Building canals, draining fens, erecting bridges, dredging harbours and developing new ports were all expensive and technically subtle projects that strained the knowledge and finances of those involved. The risks and opportunities were enormous. It was easy for technical expertise to be impugned. In this context, measures, models and demonstrations gained new significance.[5]

The shift in administrative culture under Henri IV was grounded in the *mesnagement* political philosophy of Olivier de Serres. Serres described the land

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[3] Compare to the draining of the Fens in England. See Eric H. Ash's essay in this volume. For the importance of demonstrations for ascertaining truth, see Steven Shapin and Simon Schaffer, *Leviathan and the air-pump* (Princeton: Princeton University Press, 1985); Bruno Latour 1987 *Science in action* (Cambridge, Mass.: Harvard University Press, 1987); Bruno Latour and Michel Callon, 'Don't throw the baby out with the Bath school,' Andrew Pickering, ed., *Science as practice and culture* (Chicago: University of Chicago Press, 1992), pp. 343-368. And for the connection of demonstration to politics, see Claude Rosental, 'Une Sociologie des formes de démonstration,' *Mémoire pour l'habilitation à diriger des recherches* (2004), particularly section II.2; Patrick Carroll, 'Science, power, bodies: the mobilization of Nature as state formation,' *Journal of historical sociology,* 9 (1996): 139-167.

[4] Janis Langins, *Conserving the Enlightenment: French military engineering from Vauban to the Revolution* (MIT Press, 2004); Sebastian LePrestre Vauban, *A manuel of siegecraft and fortification*, Rothrock, trans. (Ann Arbor: University of Michigan Press, 1968, originally published in 1740)), particularly pp. 121-136; and Albert de Rochas d'Aiglun, *Vauban, sa famille et ses écrits ses oisivetes et sa correspondance. Analyse et extraits*. Tome I. (Genève: Slatkin reprints, 1972).

[5] See Claude Rosental, *La Trame de l'évidence: sociologie de la démonstration en logique* (Paris: Presses Universitaires de France, 2003) on demonstrations as 'things' drawing people together.

of France as a great estate that could be rationally organised and systematically managed for the well being of the kingdom. Engaging in 'works' was a way for good Christians to restore the world to its intended, more perfect form. Serres wrote that successful land management demonstrated the virtue of the ruler, making visible the natural intelligence given good men by God. Knowledge of God could be achieved through study of his works, and engaging in human works that properly restored His plan. Demonstrations and verifications in oeconomy, in other words, were means of seeking truth through works.[6]

Under Louis XIV, the minister of the treasury, Jean-Baptiste Colbert, reappropriated the philosophy of this earlier administration, and used it to build France into a territorial state. The language of *mesnagement* was submerged under political representations of France as the new Rome, and stewardship was reconceived as oeconomy or an ancient form of intelligence. Engineering France into a political territory was a way to demonstrate a capacity to build and lead a new empire created in the image of the ancient one. Power, land engineering, demonstration and verification were intertwined in France as principles of government, and measures of its success.[7]

During this reign, an unlikely suspect, Pierre-Paul Riquet, the commissioner general of the salt tax for Languedoc and Rousillon, proposed to build a canal to run north of the Pyrenees, joining the Mediterranean and Atlantic through the Garonne River.[8] This enterprise was not surprisingly an object of

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[6] Olivier de Serres, *Théâtre d'agriculture et mesnages des champs* (Genève: Mat Hiev Berjon, 1611). See also Olivier de Serres, *The perfect use of silk-wormes* (London, 1607. Amsterdam and New York: Da Capo Press, 1971), and the earliest French book on *mesnagement*, Charles Estienne, *Maison rustique or the country farme. Compiled in the French tongue by Charles Stevens and John Liebault, Doctors of Physicke. And translated into English by Richard Surflet Practioner in Physicke* (London: Printed by Arnold Hatsfield for John Norton and John Bill, 1606). For the importance of oeconomy in this period in England as well as France, see Richard Drayton, *Nature's government: science, imperial Britain, and the 'improvement' of the world* (New Haven: Yale University Press, 2000). For an analysis of *mesnagement* estate books, and religious conflict, see Chandra Mukerji, 'Bourgeois Culture and French gardening in the sixteenth and seventeenth centuries, Michel Conan, ed., *Bourgeois influences in garden design* (Washington, DC: Dumbarton Oaks Press, 2002), pp. 173-188. For the on-going importance of oeconomy to power, see James Scott, *Seeing like a state* (New Haven: Yale, 1998); William Cronon *Nature's metropolis* (W. W. Norton, New York, 1991); Patrick Joyce, *The rule of freedom* (London: Verso, 2003). Similar motives shaped the draining of the Beemster Polder. See Alette Fleischer's essay in this volume.

[7] Compare this to Patrick Carroll's arguments about engine science and engineering from this period. See Patrick Carroll-Burke, 'Tools, instruments, and engines,' *Social studies of science* 31 (2001): 593-625.

[8] The major books describing this history are the four volumes of papers edited by Jean-Denis Bergasse, the large collection of plans for the canal by the Conseil d'Architecture, and the monographs by Maistre and Rolt. See Jean-Denis Bergasse, *Le Canal du Midi* (Cessenon: J.-D. Bergasse,

controversy, given the entrepreneur's apparent lack of qualifications for the job. Contests over knowledge and the authority to know swirled around this ambitious and invasive project. [9] Models, demonstrations and verifications became weapons in this sustained battle over the canal and Riquet's capacity to make it work.

The Canal du Midi or the Canal Royale des Deux Mers was dug across Languedoc in the 1660s-1690s. By connecting to the Garonne River near Toulouse at one end, and to the Mediterranean Sea at the other, it was supposed to allow French boats to by-pass Gibraltar and move between the two seas. The canal itself required a hundred locks, and a vast array of bridges, aqueducts, dams, water intakes, drains, as well as ports. It had to cross rivers, and weave through mountains, and employed vast water resources to float ships across the countryside of south-western France.

There were many reasons for locals to doubt or oppose the project. Long ribbons of land were indemnified by the king and turned over to the local tax farmer. Nobles were also unhappy with the increasing demands for resources and obedience from the northern monarchy, and were not pleased to give up so much of the region's resources to a project demanded by the king.[10] And while the Canal du Midi was under construction (over thirty years), large portions of the channel were dug but not filled as other parts of the waterway were being readied. This left muddy, abandoned worksites in rural Languedoc that cut across roads, orchards and fields.

The Canal du Midi was very ambitious for the period, but not without precedent as an object of engineering or political controversy. A navigational canal in Languedoc had been proposed but rejected under Henri IV. The smaller Canal de Briare near Paris was started instead, and was (not surprisingly) stalled by local opponents after the death of that monarch – only to be completed in the mid-17th century.[11] What were needed to start the Canal du Midi were the

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1985-6); Conseil d'Architecture, d'Urbanisme et de l'Environment de la Haute-Garonne, *Canal Royal de Languedoc: le partage des eaux* (Caue: Loubatières, 1992); André Maistre, *Le Canal des Deux-Mers* (Paris: Privat, 1998); L.T.C. Rolt, *From sea to sea* (Ohio University Press, 1973). Rolt describes Riquet's office for the gabelle as commissioner general, p. 69.

[9] Charles Tilly, *Politics of collective violence* (New York: Cambridge University Press, 2003); *Contention and democracy in Europe 1650-2000* (New York: Cambridge University Press, 2004).

[10] For another example of local intervention by the state to unify and manage French territory, see the forest reform in Michel Deveze, *La grande réformation des forêts royales sous Colbert, 1661-1680; une admirable réforme administrative* (Nancy, École Nationale des Eaux et Forêts, 1962), pp. 211-229, and CNRS, *Histoire de l'administration Française, Les Eaux et Forêts du 12e au 20e siècle* (Paris: Editions CNRS, 1987). For local opposition in Languedoc to central authority, see William Beik, *Absolutism and society in seventeenth-century France: state power and provincial aristocracy in Languedoc* (Cambridge: Cambridge University Press, 1985).

[11] L.T.C. Rolt, *From sea to sea*, pp. 17-24.

confidence of the king and Colbert, and the financial support of the treasury. These were attained (and opposed) with models, demonstrations and verifications that addressed the risks of the project.

The mock-ups

In November 1662, Pierre-Paul Riquet wrote to Colbert. The two were already in correspondence about the new tax farm in Rousillon:

> I wrote to you from Perpignan the 28th of last month about the imposition of the salt tax in Rousillon. And today I am writing again from this village, but on a subject distant from that one. It is about the design of a canal which could be made in this province of Languedoc for the communication of the two seas, the Atlantic and the Mediterranean.[12]

Riquet immediately conceded that he had no real expertise to do this kind of work, but made his proposal worthy of further consideration with the following remark: 'But you will excuse my boldness once you understand that it is under the command of the archbishop of Toulouse that I write you'.[13]

Riquet presented Colbert both with his project and a basis for trust. The archbishop of Toulouse, d'Anglure de Boulemont, was a powerful and respected man, and a patron not to be ignored. He would not (in principle) promote a project that he felt was ill-conceived. The cleric likely recognised the economic and political potential of the project to his region. He surely also wanted to promote a good Catholic for such an important job. A Huguenot engineer from the university at Castres, Pierre Borel, had already tried to build a canal to link the Garonne and Aude rivers in Languedoc, and had only failed because of local opposition, not a lack of ability. In late 1662, it was a good time for the archbishop of Toulouse to help Riquet, if the tax man could prove he knew what he was doing.[14]

The crucial engineering problem for the canal was a water supply system. The canal had to cross between watersheds that drained into the two seas. Without a source to flood the high point, there was no hope of keeping the locks filled and the canal working. Riquet employed a young *fontainier* from Revel, Pierre Campmas, to bring water from the Montagne Noire.[15] This was

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[12] Riquet à Colbert À Bonrepos, le 15 novembre 1662. ACM 20-2.

[13] *Ibid.*

[14] For Pierre Borel and his engineering schemes in the vicinity of Castres, see L.T.C. Rolt, *From sea to sea*, pp. 23-24. And for the archbishop and his relationship both to the Canal du Midi and the town of Castres, see Ibid., pp. 33-41.

[15] Chandra Mukerji 'Women engineers and the culture of the Pyrenees,' in Pamela H. Smith and Benjamin Schmidt, eds., *Knowledge and its making in Europe, 1500-1800* (University of Chicago Press, forthcoming).

Ill. 21. Water supply in the Montagne Noire, ca. 1670, showing Castre(s) and the connection to the main canal. Courtesy of Archives centrales de la Marine.

a place familiar to the cleric. When Riquet first approached d'Anglure de Boulemont, he was not yet the archbishop of Toulouse, but the bishop of Castres, the town in the Montagne Noire where Pierre Borel had taught engineering. The cleric was fully aware that there were nearby rivers that could be tapped for such a purpose, and that a canal would surely be tried again. All Riquet needed to do was to demonstrate that he could find people to design and build the combination of structures and channels needed for the canal.[16]

To secure his patron's trust, Riquet prepared a demonstration. On his estate at Bonrepos, Riquet built a mock-up or model with a miniature water supply, weirs, locks and other technical elements needed for the canal. He did not simply argue for the feasibility for the project to d'Anglure de Boulemont; he demonstrated that he and his colleagues had the knowledge to build it.[17] The mock-up spoke in the language of *mesnagement* politics. If the estate was a microcosm for the macrocosm of the state, what could be built on a gentleman's lands could be realised for France.[18]

[16] L.T.C. Rolt, *From sea to sea*, pp. 33 and 38 for Riquet's early solicitation of Boulemont, and the power this gave him when this local clergyman became a regional power.

[17] Ibid., pp. 37-38.

[18] Chandra Mukerji, *Territorial ambitions and the gardens of Versailles* (Cambridge: Cambridge University Press, 1997).

The strategy was persuasive. The archbishop agreed to present the project to Colbert and threw his substantial weight behind the construction of the Canal du Midi.[19] Still, the project could not advance until Riquet's measurements were verified.

The Commission

After receiving and considering Riquet's letter, Colbert assigned a commission of experts to verify the project. The group was to be led by the *inspecteur général des fortifications* (the head military engineer for France), the Chevalier de Clerville. The commissioners were asked to walk along the proposed route for the water supply in the Montagne Noire, making surveys and measuring elevations. What had been demonstrated as a possibility now had to be verified by experts and witnessed by notables. [20]

Verification entailed not only measurement, but also testifying to the accuracy of the measures. Computing elevations and distances was not enough to be convincing. Knowledge was a matter of authority, so local political elites had to witness the field measures. Soon the men of quality from Toulouse and Montpellier assigned to the commission became tired of travelling through the rough mountains, and bored with the tedious surveying. They left Clerville, the surveyors and engineers on their own, having witnessed the care with which the measurements were made.[21]

Although Riquet's project was vindicated by the study, his plan was not adopted without further demonstration. The commissioners asked Riquet to make a ditch, a *rigole d'essai*, along the proposed route from the Montagne Noire to Naurouze, where the water was meant to reach the high point of the canal. This test *rigole* was to prove the inclines. Torrents of rain slowed construction, but in October 1665, the waters arrived as expected at Naurouze, and the demonstration and verification of the alimentation system were complete. [22]

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[19] L.T.C. Rolt, *From sea to sea*, p. 38.

[20] Gazelle in Jean-Denis Bergasse, *Le Canal*, vol. 4, p. 145-146; M. L. Malavialle, 'Une excursion dans la Montagne Noire,' Part I. *Société Languedocienne de Géographie Bulletin* 14 (1891): 280-284.

[21] L.T.C. Rolt, *From sea to sea*, pp. 42-43. For demonstrations and enrollment, see Claude Rosental, *La Trame de l'évidence*.

[22] L.T.C. Rolt, *From sea to sea*, pp. 35-37; Froidour, pp. 9-10. See Chandra Mukerji, 'Entrepreneurialism, land management and cartography during the age of Louis XIV,' Paula Findlen and Pamela H. Smith, *Merchants and marvels* (New York: Routledge, 2002), pp. 248-276 for more details about the politics of developing the water system.

The contract

The *Arrest de Conseil* of 1666[23] defined the terms of the contract for building the Canal du Midi. It specified the obligations of the treasury and contained the estimate for the work and plan of construction written by Clerville. It also set out conditions for accessing monies from the treasury. These included on-going 'verifications' of the acquisition of lands and progress of the canal.

The canal was given a budget of 3,630,000 livres to be allocated over eight years in sums of 453,750 livres per year. If the project was not completed in eight years, the treasury and Etats de Languedoc had no further responsibility to the entrepreneur. The money from the treasury was to be set aside immediately for the project, but it would not go directly to Riquet. It was kept by the bourse in Languedoc. This body would disperse allotments annually, but only after the work was properly verified.[24] A permanent commission was set up to oversee the project and to choose experts to do the verifications. Importantly, the king and Etats both would not pay them for the costs, leaving this expense to the entrepreneur.[25] The deadline, the selection of experts, the verification process itself and the lack of funds for doing the studies provided opponents many ways to impede work on the canal.

The indemnities paid local landholders for confiscated parcels also required verification. The amounts were to be set by experts appointed by the commissioners. The majority of gentlemen of the Etats were hostile to the canal and sympathetic to locals – both nobles and communities – whose modes of life were disrupted by the work. They did not want their counterparts and allies to lose lands or money, so they made the process of indemnification difficult. The monies first tendered for land were (not surprisingly) considered insufficient,

23 Le 14 octobre 1666, *l'Arrêt d'adjudication des ouvrages à faire pour le canal de communication des Mers en Languedoc est promulgué. Ce même jour, le Roi 'fait bail et délivrance à M. de Riquet des ouvrages contenues au Devis' préalablement défini sous l'autorité du Chevalier de Clerville*. ACM 03-10.

24 Arrest of 1666, pp. 20-21.

25 See Andre Maistre, *Le Canal des Deux Mers*, pp. 55-57. In a letter from Bordeaux in May 1669, Clerville offered to come look at whatever Riquet wanted him to see, and asked the entrepreneur to pay his expenses. ACM 31-25. One of the verifications he did make after M. d'Aguesseau became intendant for Languedoc in 1673 is a detailed inventory of all the major worksites, commentary on their status given M. d'Aguesseau by Riquet, and Clerville's review of the work completed in these areas. (ACM13-12) For an example of a different sort of verification, less like an account book, there is a 1672 review of work on the water supply system. New and deeper *rigoles* were being dug then, and some of the connections to rivulets and rivers were being fixed. Drains were being installed to get rid of excess water, and return it for use by locals. See the untitled document, ACM13-07. There is also another verification done by the sieur de Montbel in 1674 for payments to property holders near the canal. See ACM 96-13.

and new verifications were demanded to take into account the difference between improved and unimproved parcels. The Etats agreed that land that had mills, orchards, roads or other amenities should be given higher value than undeveloped land. So, these attributes had to be inventoried and verified in the areas claimed for the canal.[26] Given the eight year limit to the contract, calls for new verifications seemed to threaten the project by slowing the acquisition of lands and release of funds. Verifications became tactical weapons in the hands of the reluctant nobles of Languedoc.

Demonstrations and verifications, although clearly political, worked best if the results were precise.[27] Political ends were easier to achieve with empirical bases for them. For opponents, there were plenty of problems in building the canal that they could document, and taking time to look at them brought the deadline closer. For Riquet and his collaborators, it was often possible to demonstrate achievements and provide solutions to problems that loomed large for opponents. So, verifications could and did address matters of fact for both sides. The value of an orchard and the productivity of a mill were matters of demonstration and verification. The length and shape of the canal's channel were also empirical issues. Knowledge was served rather than undermined by the recriminations and accusations that circulated around the canal as proponents and opponents alike called for evidence. Passion and dispassion were productively linked.[28]

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[26] See Andre Maistre, *Le Canal des Deux Mers*, pp. 50-51, 57-58. In spite of the original deadline, the contract for the second enterprise gave Riquet more time to finish the canal. This is why in 1679 the Etats were still negotiating with the king about what and when to pay for the canal. This included indemnification. ACM 96-19, 'Extrait du Cayer de deliberations pris par les gens des trois Etats de la province du Languedoc… 12 janvier 1680' as well as the 'Extrait' mentioned above ACM 96-13 from 1674. But already in November of 1672, the Etats are arguing that the canal has taken so long that they no longer have faith that the canal will be completed and serve the region and its commerce. See 'Extrait du Cayer des Deliberations'18- 28 Nov 1672 (ACM 96-11).

[27] An untitled and undated document (but probably written in 1677) ACM 12-09 describes how much the lack of funds has slowed down work on the canal. It also documents the extraordinary expenses (unanticipated ones) that made the canal a financial disaster for Riquet and his family, referring to two other documents, 'Travaux extraordinaires faits par feu Monsieur Riquet….1677' (ACM12/05, 12-07). Riquet's letter from Clerville with an unclear date (ACM 31-43) expresses the opinion that the king and Colbert are very pleased with Riquet's zeal, and would be unhappy if a lack of funds from the bourse would slow the project even more than it already has. In a postscript, he says he will meet Riquet the following Monday – possibly for a new verification of the canal.
For more contemporary examples of the importance of scientific precision to political practice, see Chandra Mukerji, *A fragile power: science and the state* (Princeton: Princeton University Press, 1990). And for a discussion of social epistemology, and how debates over truth can serve rather than impede the search for truth, see Helen Longino, *Science as social knowledge* (Princeton: Princeton University Press, 1990).

[28] Martha Nussbaum, *Upheavals of thought* (Cambridge: Cambridge University Press, 2001).

Not surprisingly, it was easier to measure elevations than to obtain treasury funds. Riquet wrote to Colbert on 27 fevrier 1667, five months after the *Arrest de Conseil* and five years after Riquet first raised the question of the canal:

Given that I have not yet touched funds other than my own, and that I dare expect no more this year than the sum of 50,000 livres of the 300 million to be given to the province by the king over eight years for the canal… I am so passionate about seeing a happy and quick ending to my enterprise that I continue to work vigorously. So much so that I have spent great sums [of my own] this year. If it were possible for me to continue this way, I would achieve in four years what I have promised in eight. I wish I had the proportionate finances. It is because [I do not], that I am resolved to come to Paris next November to show you the account books, if you agree to what I am proposing…If it pleases you, sire, send me back with a bill for the province for the sum of 150,000 livres with a letter from you to the treasurers of the bourse obliging them to pay me without delay… [and demanding] that I receive payments from the funds designated for this work at the beginning of each year. Because without such a letter, the messieurs [of the Etats and bourse] will hold onto the payments until the end of the year… and I am too far into debt not to pay up…. I have already spent twice as much on the canal this year as was allocated…. I need your protection and help.[29]

Colbert was quick to reassure the entrepreneur, but still looked into the opponents' reasons for keeping the funds from Riquet.[30] He found that the tax farmer was in arrears in depositing his tax monies with the Etats. The bourse had responded by impounding funds for the canal. On the 27th of April, Colbert wrote Riquet:

Sir, having examined for a little while the monies which are due to the Royal Treasury by the tax farmers, and other charges about the recovery of taxes, I have found that you are in arrears by the sum of 349,784 livres 5 sols. And since the summer months that we are entering are near and moreover the amount due is considerable, I ask you to acquit promptly the [missing] part [of the taxes], being persuaded that having paid regularly until now and the king being satisfied [with your conduct so far], you would not want to put an end to his [good will toward you]. In awaiting your response, I remain, sir, you very affectionate servant….[31]

Riquet seemed to have been paying bills for the canal with his tax income even though this was not the case. The tax man deposited the required monies and

[29] ACM 20-28, Riquet à Monseigneur Colbert Le 27 fevrier 1667.
[30] ACM 20-32, Monseigneur Colbert à Riquet A Saint Germain, le 1er avril 1667.
[31] ACM 20-36, Monseigneur Colbert à Riquet A Saint Germain, le 27 avril 1667

regained some of Colbert's trust, but not all. Colbert started to question his word. Trust and knowledge were intertwined, so the loss of trust limited Riquet's ability to advocate for the Canal du Midi, or testify to its progress. Rumours about his incompetence and lack of trustworthiness continued to erode his relations with Colbert. In 1669, the minister sent an engineer he could trust, a M. de la Feuille, to become his eyes and ears for the project. This courtly gentleman had the social stature to be taken at his word.[32]

This apparent slap in the face was not immediately bad for Riquet. When the Sr. de la Feuille was involved in the verifications, Colbert took them more seriously, and some funds trickled out from the bourse. But the flow of money was small. Still in 1674, for example, the Etats agreed to pay Riquet some small portion of what he wanted, still refusing the release the rest of the annual stipend because not all the indemnifications had been paid.[33]

The route by Toulouse

The design of the canal remained at issue even after the project as a whole was approved. Clerville, who recognised that solutions to many problems would have to be discovered along the way, was willing to leave some details unspecified. The new proposals were subject to technical debates (and used for character assassination on technical grounds). Again they depended on demonstrations and verifications.

An example was the plan for connecting the Canal du Midi to the Garonne by Toulouse. Riquet proposed to run his canal into the city moat, and from there to the Garonne River by the porte du Bazacle. Next to the river, he would build a new port that could shelter boats when the river was running high. This proposal was given to the Capitouls, the city fathers, who had it assessed by their expert, Jean Nivelle.[34] Both text and commentary were published as the *Avis a messieurs les Capitouls de la Ville de Tolose, par Arquier, Doyen des anciens Capitouls*. This text was presented in two columns, one with the

[32] For evidence of Colbert's support of the project, but anxieties about Riquet, see a letter from Clerville to Riquet 26 avril 1669 (ACM 31-26). For the arrival of the sieur de la Feuille, see L.T.C. Rolt, *From sea to sea*, p. 76.

[33] ACM 96/13. Riquet continued in 1668 to submit accounts of his expenses in the hopes of getting reimbursed. See Riquet à Monsieigneur, 1668 (ACM 7-02). Riquet's inability to access these funds pushed him to find new ways to raise money for the canal. The town of Castelnaudery wanted him to take the canal by their town, and make a harbor there. For this they paid the entrepreneur 6,500 livres. See 'Extrait de … Conseil d'Estat…' 1671 (ACM11-01) that describes the king giving formal approval to this change in the plan in 1670.

[34] Andre Maistre, *Le Canal des Deux Mers*, p. 47

proposal from Riquet presented by one of the *Capitouls*, M. Arquier, and the other containing commentary by Nivelle.[35]

Arquier began by presenting Riquet's ambitious hopes for and inflated rhetoric about the canal.

The project of the king to build a royal canal for the communication of the two seas, the Ocean and the Mediterranean, is more glorious than the conquest of many nations, since all the nations of the world will render homage to his majesty and will pay him tributes in passing through this royal canal….[This canal] is the most admirable and greatest project that has been achieved since the beginning of the world to the present for the improvement of trade, so that Languedoc and all France will be frequented by ordinary people from all the universe, and this canal will make us neighbours of the most distant provinces.[36]

In the face of the hyperbole that he would later use against Riquet, Nivelle concurred. 'Yl est vrai'. Like a spider watching a fly, he said little.[37] But Riquet's plan to run the canal through the town moat was a different story. Nivelle was contemptuous of the idea and the man who proposed it:

One is convinced that the waters [in this region] all drain into the moat [as Riquet suggested in his plan], and that's the reason why it is a particular *problem* to place the canal in this area. It will increase the need for constructions to control flooding…. *Notice that the true author [Riquet] of this article and of the following ones, presents fictions, which have more in common with fables [romans] than with facts [histoire].* One doesn't know how to respond to proposals in cases like this where measurement and verifications should be worth more than discourse. (emphasis added)

While accepting that Riquet knew something of the inclines approaching the moat near Bazacle, Nivelle argued that the entrepreneur had overlooked the risks posed to the town by floods from this direction. He could argue that Riquet was dreaming up schemes rather than really studying possibilities because the proposal to the Capitouls contained no measurements of the slopes to verify the feasibility of the plan. Instead, Arquier (Riquet?) testified that the plan had been demonstrated physically on the land itself. If Riquet had worked up the plan with the help of Pierre Campmas, the *fontanier* from Revel, it would explain why the plan was based on tacit knowledge rather than formal measures. In any case, this evidence did not convince Nivelle.

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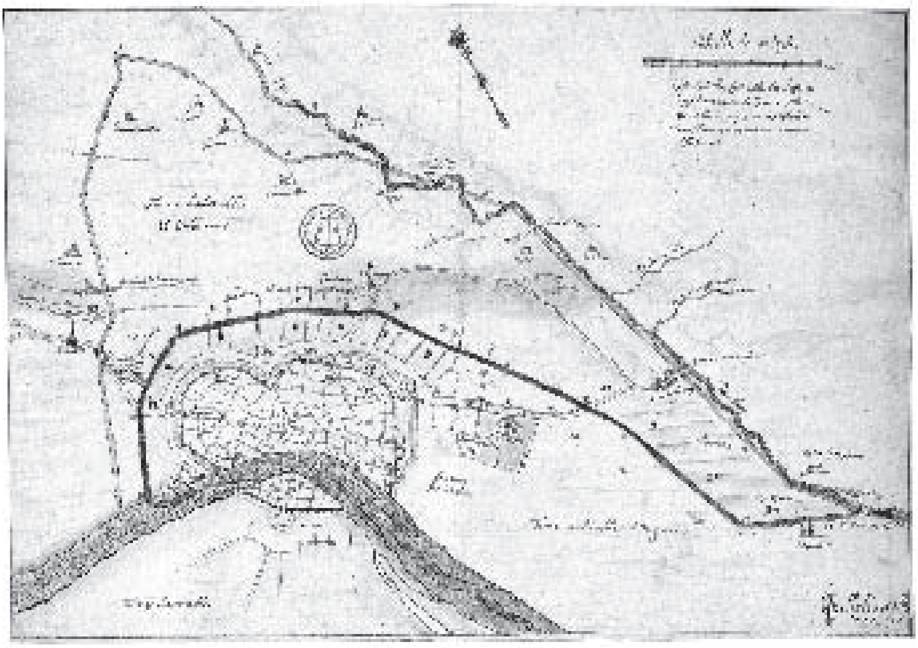
[35] *Avis a messieurs les capitouls de la ville de tolose, par arquier, doyen de anciens capitouls. Et response a cet avis, article par article par Jean de Nivelle, ancien capitaine chasseauant du canal dans l'atelier de Mr. Sagadenes.* 1667. ACM 01-16

[36] *Avis a messieurs les capitouls*, ACM 01-16.



Ill. 22. Plans for connecting to the Garonne near Toulouse, showing the moat, the suburban route and the final and most remote route around the city. Courtesy of Archives centrales de la Marine.

When Riquet proposed to build a new port where the canal met the Garonne, Nivelle was even more dismissive; the plan was not even worthy of debate:

This is nothing but an idea, and one of enormous expense. It is better to ignore it than to talk of it. It is quite easy already for patrons who come from Bordeaux to go to the port that has been their ordinary destination over the centuries…The entrepreneur for the canal, although he can say it is possible to extend a canal from his canal and run it to the Garonne, descending through a lock into the river by the mill of the chateau,…that does not mean it is really possible. *He does not understand what other men comprehend that our knowledge of engineering does not extend to this*. There no knowledge of how to make the water go down this way…. There are no machines or tunnels adequate for this. (emphasis added)

Nivelle attacked the proposal in part because Riquet had refused to do what the Capitouls wanted: to run the canal into the Lers River, improving the riverbed for navigation. This would have routed the canal through the cheaper land along the river, not the more desirable properties on the adjacent hillsides.[38] Instead

[37] *Avis a messieurs les Capitouls*, ACM 01-16.
[38] L.T.C. Rolt, *From sea to sea*, p. 69.

Riquet had proposed to run the canal just below the lands of the president of the Capitouls. While this would have improved the commercial potential of these lands, it also would have made Riquet a neighbour who might find reason to 'need' more nearby parcels. This was not an attractive prospect.

The president of the Capitouls and his colleagues had no desire to accept this plan. Nivelle was their technical expert. To argue their case, Nivelle used his knowledge of contemporary engineering, dismissing the canal as a delusional fiction rather than a verifiable possibility. That Riquet had proposed new solutions to technical problems was presented not as an asset, but rather an indication of his naïveté.

> All of what is in this proposal is fabulous, equally part of the estimate [*devis*] where the text is false. The discourse is beautiful and reports history accurately, but Riquet makes up monsters in order to defeat them [to argue for the canal]. It is fair to say that the author of this proposal is full of zeal for the public good, but he apparently does not know anything, nothing of water, nothing of canals, nor does he know anything about locks, or even that the canal would have to cross the river Lers to get to Toulouse.... *The arguments presented here without verification are bad ones, because they lack the most important basis, that is, telling the truth*. The entrepreneur for the canal has reason to advance his projects without resorting to fictions; *if he continues this way, he will never see the end of this work*. (emphasis added)

Riquet and Nivelle were interested parties to the project; the latter was as happy to defame the former rhetorically as Riquet was glad to tout his plans. Still, they spoke about the truth of things. Riquet considered local topography in his plan, even though without elevation measures. He also recommended techniques being used to build the new port at Sète to construct one for Toulouse. Nivelle sneered at these proposals, but they had some sound basis. On the other hand, Nivelle asked good questions. Flood control was a perennial problem for the canal. Taking the canal over rivers and streams also required technical invention, and led finally to the design of *pont-aqueducs* or aqueduct bridges to carry the canal over flood-prone valleys. When Nivelle argued that Riquet proposed a canal that was beyond the technical capacity of engineers in the period, he was also right. But that was the point. Nivelle could only protect Toulouse from the Canal du Midi by posing valid questions. And Riquet had to promote his project by calling for the novelties that were not yet recognised by engineers. Nivelle could legitimately define Riquet's plans as fictions. And Riquet could only (finally) demonstrate the validity of his proposals in the canal itself. But Nivelle threatened, 'if he continues this way, he will never see the end of this work'.

After this brief skirmish, the Canal du Midi was finally routed around the city, meeting the Garonne in the suburbs west of Toulouse. Local opponents had succeeded in changing the route, but not stopping the canal. At the opening ceremonies for the port on the Garonne, the Capitouls and other notables were present. They helped celebrate an icon of the new Rome that they had hoped would fail completely:

On the 17th of November, the notables of the town, the ancient and new Capitouls dressed in red and black, the clergy and Parliament in grand attire with all the attributes of their rank, paraded to the walls of the capital city of Languedoc. They met there the workers for the canal, without whom nothing would have been accomplished…. They shouted out cries of joy, 'Vive le Roy,' or in the words of the author of the Annales de Toulouse, '[they] formed a kind of amphitheatre and provided a sense of the spectacles of the ancient romans'. [This] perfect assembly of the powerful and honourable members of society … came to the place for the foundation of the locks [to link the canal to the Garonne]. The archbishop of Toulouse took the first two stones in his hand. He blessed them, giving one to the president of Parliament (the legal system that constitutes part of the importance of Toulouse) and the second to the Capitouls (the municipal powers). A little mortar was taken with a trowel of gold from a silver plate, and the stones were placed.[39]

No matter what opposition had been raised by the Capitouls to bringing the canal into their city, as servants of the king, they officially embraced what was built.

Ironically, one of the greatest failures of the canal took place at or near the site where the ceremony took place. The walls of a lock near the river were built too deep and started to collapse. Scaling up the locks from models made them vulnerable.[40] Riquet had produced successful miniatures at Bonrepos, but the tall walls of the locks near Toulouse started to buckle under the forces of the earth pushing against them. A staircase of locks was built to replace the one that failed.[41]

Building the canal remained an empirical matter. It was an experiment and sometimes produced surprising results. Subsequent locks along the Canal du Midi were given an oval form that was more sturdy, and many locks first built with straight walls were taken down, and replaced with oval ones. Clerville and

[39] Matthieu de Mourgues *Relation de la seconde navigation du Canal Royal*, 1683, quoted by Phillippe Delvit on pp. 204-205 in 'Un Canal au Midi,' Conseil d'Architecture et al., *Canal Royale*, pp. 204-224. Mourgues' position as *inspecteur du canal* in this period is described by Dainville 1961, p. 53 in relationship to the maps of Montaigu commissioned by Colbert to keep track of the canal project in the 1680s. Dainville chronicles the difficulties of trying to use maps for 'action at a distance'. See François de Dainville, *Cartes Anciennes du Languedoc XVI^{e}-XVIII^{e} S.* (Montpellier, Société Languedocienne de Géographie, 1961), pp. 50-55.

[40] On the problems of scaling up from models, see the essays by Lissa Roberts and Simon Schaffer in this volume.

[41] L.T.C. Rolt, *From sea to sea*, pp. 70-75.

Andreossy verified the new work, and Andreossy, the original engineer for the canal, was made the supervisor or *controlle* of the part of the canal in the vicinity of Toulouse.[42] Both technical and organisational repairs were complete, and a complex internal system of verification was put into place.

Conclusion

The Canal du Midi was built from water, brick, stone, mortar, mud, timber and contentious politics. It was an experiment in creating a territorial state through engineering and intelligent land management. Demonstrations and verifications linked the physical structure to the political process, transforming the power of places and the places of power. As weapons of political warfare, demonstrations and verifications could be used equally well for or against a project like the Canal du Midi because it entailed so many technical innovations and social risks.

Even beyond the canal project, the aristocracy of Languedoc was determined to preserve its authority and powers in the face of an invasive northern monarchy. Notables were using the advantages of social rank as best they could to defend their traditional powers and habits.[43] Men of the Etats, clerics and nobles alike, had an authority to know that Riquet, as a state functionary, could never match. If their experts said a plan was no good, this mattered. When such notables argued for the canal, it made some progress. The political process was cumbersome, but required Riquet to recognise their powers even as he tried to change the region they governed. Even if they liked Riquet and his plans, they were wary of state encroachment.

At the same time, oeconomy in the *mesnagement* tradition provided a powerful rationale for state intervention in the province; land use in religious terms was meant to express the intelligence given men by God to exercise dominion over the earth and its creatures. Building a more peaceful waterway through Languedoc with its wild rivers fell easily into this logic of governance. [44]

In this context, demonstrations and verifications had to be precise and empirical, vetting the plans for problems (if not anticipating all of them). Demonstrations and verifications were used to determine matters of fact and the authority of those who argued them. For men like Riquet without the social rank to assure trust in their ideas, these forms of public examination were tortuous but necessary parts of the political process. These were the techniques that could give him authority to proceed and release the funds for it.

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42 A.C.M. n° 17-12, *Memoire des choses necessaires*.

43 Beik, *Absolutism and society*.

44 For comparison with contemporary projects in England and the Netherlands, see the essays by Eric Ash and Alette Fleischer in this volume.

Many demonstrations and verifications required for the Canal du Midi ended up as quiet struggles with few witnesses, but they addressed the elites and experts who were important to the process. They were not public like the scientific spectacles in Paris that drew crowds of interested men and women. The commissioners' walk along the Montagne Noire was not widely visible outside the mountain, but it still produced demonstrable, verifiable facts that were effective for enrolling allies.[45] Like many subsequent verifications, the results were published and became matters of public record.

The Canal du Midi itself became the final demonstration of the factual bases of Riquet's fictions. It led to the subsequent celebration of Riquet as a local genius who had beaten his adversaries by achieving his ends. But in his own time, the entrepreneur was a dreamer who needed to be watched, and a tax farmer who would stubbornly pursue his own interests and could only be partly trusted with money.

The elaborate choreography of demonstration and verification required for the Canal du Midi functioned as tools of social surveillance as well as of technical competence. Riquet wielded too much power for a state functionary. Oeconomy was a potent and dangerous source of change in this period of early French territorial politics, and Riquet was the visible agent of it. If verifications limited his possible actions and repeatedly required him to show obeisance to the Etats and the treasury, the power of demonstration remained too clearly on his side. His dreams were too potent; his ambitions too great. As the project progressed, he became an increasingly dangerous man to the minister, not a more trusted and valued one. As Colbert put it, even after much of the canal was in use:

> …we must, nevertheless, apply ourselves with care in order that the course and strength of [Riquet's] imaginings do not bring on us a final and grievous end of all his works….This man does as do great liars who, after telling a story three or four times, persuade themselves it is true.[46]

The power of engineering could make real the personal dreams of men of ambiguous social standing like Riquet. Mere functionaries could change the conditions of life for even the nobility when they had the power to refashion the countryside. Knowing what could be *done* was not the same as academic knowledge, but it could be proved by experiment – by demonstration. When a financier like Riquet built part of the 'new Rome' from the tacit knowledge of the people in Languedoc, he built more than a piece of state infrastructure.[47]

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45 Claude Rosental, *Mémoire*.

46 Colbert's letter to d'Aguesseau in 1677 quoted in Rolt, *From sea to sea*, pp. 91-92.

47 Chandra Mukerji, 'Women engineers'.

He demonstrated how realities could be made and proved at the same time by men of questionable standing and little authority for speaking the truth.

Primary sources

'Avis a messieurs les Capitouls de la Ville de Tolose, par Arquier, Doyen de anciens Capitouls. Et Response a cet Avis, Article par Article par Jean de Nivelle, Ancien Capitaine Chasseauant du Canal dans l'atelier de Mr. Sagadenes'. 1667. (ACM n° 01-16).

'Estat auquel le Chevalier de Clerville a trouvé les ouvrages du canal de la jonction des mers…' n.d. (ACM n°13-12).

Estienne, Charles, *Maison rustique or the country farme. Compiled in the French tongue by Charles Stevens and John Liebault, Doctors of Physicke. And translated into English by Richard Surflet Practitioner in Physicke* (London: Printed by Arnold Hatsfield for John Norton and John Bill, 1606).

'Extrait du Cayer de deliberations pris par les gens des trois Etats de la province du Languedoc… 12 janvier 1680' (ACM n° 96-19).

'Extrait du Cayer de deliberations prises par les gens des trois Etats de la province du Languedoc assemblés par Mandement du Roy a Montpellier le quinze Novembre, mil six cents soixante quatorze'. (ACM n° 96-13).

'Extrait du Cayer des Deliberations prises par les gens des trois Etats de la province du Languedoc…'. 18- 28 Nov 1672 (ACM n° 96-11).

'l'Arrêt d'adjudication des ouvrages à faire pour le canal de communication des Mers en Languedoc est promulgué'. Le 14 octobre 1666, Ce même jour, le Roi 'fait bail et délivrance à M. de Riquet des ouvrages contenues au Devis' préalablement défini sous l'autorité du Chevalier de Clerville. (ACM n° 3-10).

'Travaux extraordinaires faits par feu Monsieur Riquet….1677' (ACM n° 12-05).

'Travaux extraordinaires faits par feu Monsieur Riquet…'. (ACM n° 12-07).

Extrait de.. Conseil d'Estat 1671 (ACM n° 11-01).

Lettre de Clerville à Riquet, Mai 1669 (ACM n° 31-25).

Lettre de Clerville à Riquet 26 avril 1669 (ACM n° 31-26).

Lettre de Clerville à Riquet, n.d. (ACM n° 31-43).

Lettre de Monseigneur Colbert à Riquet A Saint Germain, le 1er avril 1667. (ACM n° 20-32).

Lettre de Monseigneur Colbert à Riquet A Saint Germain, le 27 avril 1667 (ACM n° 20-36).

Lettre de Riquet à Colbert À Bonrepos, le 15 novembre 1662. (ACM n° 20-2).

Lettre de Riquet à Monseigneur Colbert Le 27 fevrier 1667. (ACM n° 20-28).

Memoire des choses necessaires. (ACM n° 17-12).

Riquet à Monsiegneur, 1668 (ACM n° 7-02).

Serres, Olivier de, *The perfect use of silk-wormes* (London, 1607. Amsterdam and New York: Da Capo Press, 1971).

Serres, Olivier de, *Théâtre d'agriculture et mesnages des champs* (Genève: Mat Hiev Berjon, 1611).

Unititled document 'Il est remarquer que dans les deux memoires des travaux extraordinaires…'. c. 1680 (ACM n° 12-09).

Untitled document 'Le Canal de communication des mers… a douze pieds de profondeur…' 1672 (ACM n° 13-07).

Vauban, Sebastian LePrestre, *A manuel of siegecraft and fortification*. Rothrock, trans. (Ann Arbor: University of Michigan Press, 1968 (originally published in 1740)).

III. Geographies of skill

Introduction

Lissa Roberts

Blinded, perhaps, by the glow of his own enlightened optimism, the Marquis de Condorcet died under the guillotine's shadow in 1794 without forsaking his dream that humanity stood on the verge of a utopian future. Condorcet imagined an epochal transformation of society in his *Esquisse d'un tableau historique des progrès de l'esprit humain*, sure to be ushered in by the advances and spread of reason. The French Revolution raged on, meanwhile, greedily devouring its children – decidedly not the revolution Condorcet had in mind. Nonetheless, a host of commentators, ranging from conspiracy theorists such as the Abbé Barruel to academic historians such as Daniel Mornet and Robert Darnton, have examined whether some kind of causal connection might be found between Enlightenment thought and revolutionary deed. And just as Condorcet emphasised the close link he perceived between the spread of knowledge and contemporary advances in the mechanical arts, subsequent historians have sought to establish a relationship between Enlightenment natural philosophy and the 'revolutionary' birth of modern industry.[1]

Even before the eighteenth century's promises of progress gave way to revolutionary upheaval, though, countless encyclopedists set out to map – often in highly charged social or political ways – the knowledge and know-how that lent the Enlightenment its name. Jean Le Rond d'Alembert announced the arrival of the greatest of these enterprises in 1751 with a preliminary discourse in which he discussed the relations between the arts, sciences and society. It made good sense to introduce a reasoned dictionary by providing clear definitions and d'Alembert did his best to oblige, distinguishing between the arts and sciences in terms of their overriding principles. Speculation, he wrote, informs the sciences; the constituting principle of the arts is practice.

[1] Marie Jean Antoine Nicolas Caritat, Marquis de Condorcet, *Esquisse d'un tableau historique des progrès de l'esprit humain* (Paris, 1795); Augustin Barruel, *Mémoires pour servir à l'histoire du Jacobinisme* (London, 1797); Daniel Mornet, *Les origines intellectuelles de la révolution française* (Paris: Colin, 1933); Robert Darnton, *The forbidden best-sellers of pre-revolutionary France* (London: Fontana Press, 1997).

Not content to leave his readers with such clear and clear-cut definitions, however, d'Alembert went on to undermine and historicise the distinction he set down. Ironically echoing the distinction he had just made, he observed that what was clear in theory was anything but clear in practice. For the streets of Paris ran black with ink spilled in debates over whether various occupations ought to be termed science or art. Strikingly, the example d'Alembert cited was logic – the paradigmatic discipline of university scholars. Perhaps it was best, he remarked, simply to say that such fields were simultaneously science and art.

Whether intended as a jab at contemporary pretensions, d'Alembert justified his own belief that many so-called sciences actually combined speculation (a kind of practice, it could easily be argued) with practice and thereby deserved equally to be labelled as art, by further elaborating his definition. An art, he continued, is a 'system of the understanding capable of being reduced to rules that are positive, invariable and independent of either caprice or opinion'. How, then, to account for proclaimed differences and construct an inclusive map of knowledge and know-how?

D'Alembert's first step was to divide the arts in two: liberal arts are governed by rules for the operation of the spirit or soul, mechanical arts by rules for operating the body. Recognising the superiority of the former over the latter as both manifest and unjust, he offered a revealing explanation for how this situation had come to pass. If the state of nature had conspired against the equally natural principle of human equality by allowing brute strength to reign over physical weakness, the oppressed sought their revenge with the establishment of society. Henceforth, the genius and guile of human intelligence asserted their dominion, relegating corporal power to the bottom of the social heap. This was, however, no simple history of the division between head and hand. D'Alembert recounted that it was poverty that forced many to take on manual work, though their talents might have otherwise directed them elsewhere. And because their employment further tainted such work with the stain of their destitution, its lowly social position was reinforced. But, d'Alembert asserted, wasn't it the case that the manual arts actually inherited their mechanical character from their great utility? Was it not extensive demand, after all, that had induced the mechanisation of their operations, enabling large numbers to practice them? And wasn't it also the case that many so-called scholars reduced, in practice, their science to a mechanical art? '[W]hat is the real difference,' he asked, 'between a head filled with facts without any order, any usefulness or any connections, and the instinct of an artisan reduced to a mechanical operation?'[2]

[2] Jean le Rond d'Alembert, *Discours préliminaire de l'Encyclopédie* (Paris, 1893; original publication date 1751), pp. 59-63.

Constructing a stable map of knowledge and know-how was no easy task, given this context of social tension and unclear borders, and we find d'Alembert's definitional and historical equivocations echoed in a number of the *Encyclopédie*'s articles. One example, especially germane to the issues raised by this section, is Gabriel-François Venel's article on chemistry (*chymie*). Venel took great pains here to demonstrate that chemistry was simultaneously a science 'occupied with the union and separation of bodies' constituent principles' and an art 'or… system of instruments and rules'. Chemistry, as affirmed by both history and his own career, married the search for knowledge to the search for profit, power and pleasure in ways that totally belied the division between head and hand. Theory building and manufacture were rooted in the same fertile space, fruitful only when systematically cultivated in the laboratory or workshop. This point was neatly portrayed in the *Encyclopédie*'s plate that accompanied Venel's article. Directly beneath a scene of orchestrated collaboration in a chemistry laboratory, the reader finds an affinity table whose systematised representation guided the sort of laboratory activity by which it had been generated.

Chemistry's productively hybrid nature was also visible in places such as the Parisian *Jardin du roi*. It was here that the apothecary Guillaume-François Rouelle taught a generation of professional and amateur chemists to uncover nature's wealth and truths by disciplining their bodies in the service of chemical inquiry. Is it a historical irony that the chemical revolution Venel called for – of which he considered Rouelle the great prophet – would give rise to a newly institutionalised priority of theory over investigative practice and the disciplined subordination of chemists' bodies to the instruments they deployed? Or that it would be implicated in a more general drive to rationalise both the processes and management of chemical production?[3]

So long as historiographical traditions lead us to organise the history of 'scientific' knowledge in terms of theory (the 'history of science') and to separate it from an analysis of its 'applications' to industry (the 'history of technology'), such trends will be difficult to apprehend. And, yet, these shifting geographies of skill are precisely what we need to recover. Struggling against the sort of historical retrospection that has accepted the division between reason and labour as natural, however, is only half the battle. We must

[3] Gabriel-François Venel, 'Chymie,' Diderot and d'Alembert, eds., *Encyclopédie* (Paris, 1753), volume 3, pp. 419-420; Christine Lehman, *Gabriel-François Venel, sa place dans la chimie française du XVIII^{e} siècle* (Thèse: Université Paris X, 2006); Lissa Roberts, 'Setting the table: the disciplinary development of eighteenth-century chemistry,' Peter Dear, ed., *The literary structure of scientific argument* (1991), pp. 111-113; idem, 'The death of the sensuous chemist,' *Studies in the history and philosophy of science* 4 (1995): 503-29.

also attend to how these landscapes were initially ordered by the complex facts and assertions of productive work, then altered by managers and savants who sought to mechanise the productive forces of nature, society and industry. As the cultural geographer Denis Cosgrove puts it, we need to think of these geographies as evolving out of tensions between the facts of human occupation and use and the 'self-conscious writing of authority across space'.[4]

While all the essays in this volume explore specific sites where inquiry and invention productively interacted, the essays in this section focus explicitly on the geographical character of these explorations. They reveal that historical actors were keen to manage the productive arenas in which they operated, aware as they were that the specific places in which goods and meanings were made mattered greatly to the complex patterns of skill's ownership and control. We learn further that assertions of ownership over production were reinforced by the ingenious engineering of relations between sites associated with intellectual, administrative and material labour. No doubt the emergence of a dominant image of pure reason as a separate and privileged factor in production and distribution was a result of such efforts.

The first essay in this section, by Lissa Roberts, begins by asking how historians can recover such geographies of skill and seeks to answer that question by charting the career of a single set of apparatus in the Netherlands during the eighteenth century. If history leaves no more than the traces of skill – embodied in the people and tools that exercised it and the products and effects to which its exercise gave rise – mapping skill's active presence requires comparative attention to the various sites in which such exercises were staged. Examining the changes in meaning, significance and use that a particular category of apparatus underwent as its examples circulated among a number of sites within a circumscribed grid of time and space provides a way of organising such comparison.

Roberts zeroes in on steam-powered contraptions (aeolipiles, steam pumps and engines) because of steam's emblematic status as the motor of modern industrialisation. Instead of a topography moulded by the diffusion of knowledge and know-how from Great Britain to the continent, however, she uncovers an international landscape engineered by appropriation and travel. In place of a chart in which theoretical knowledge and rational method informed mechanical innovation (or not), she plots a history in which the same apparatus was tied to the production and consumption of natural knowledge *and* constructive know-how, depending on the particular context in which it was skilfully deployed. Instead of a map whose image is divided by the categories

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[4] Denis Cosgrove, 'Review of Edmund C. Penning-Rowsell and David Lowenthal, eds., *Landscape, meanings and value*,' *Transactions of the Institute of British Geographers* 12 (1987), p. 369.

of production and consumption, she sketches the practical continuum to which both contributed – consumption continually and transformatively giving rise to the further production of ideas, innovations, interpretations and imaginings. And, in place of a homogeneous vista of European enlightenment, she reiterates the local character that coloured seemingly universal ideals and methods – including encyclopedism.

At first glance, the map provided by Jim Bennett's essay seems even more local than Roberts' Dutch orientation. But if his is an intense retracing of a short and fateful stroll taken by a group of London 'conspirators' on 8 September 1796, it also implies an extensive image of the global character that British commerce in both knowledge and goods lent to the people and products that populated its streets. Bennett's *dramatis personae* include a ship's doctor who sailed the proverbial seven seas, a druggist whose stock in trade included ingredients imported from exotic locales, two figures who worked with timepieces – one of the great motors of navigational advance in the eighteenth century – and a pamphleteer whose radical bookshop was a clearing house for the revolutionary creeds that criss-crossed the Atlantic along with the winds of the 'middle passage'.[5]

Geographically speaking, we might further consider the mundane site chosen by Bennett – on the surface a minor shopping expedition – as formed by a confluence of skills that included instrument making, commercial negotiation, experimental inquiry and social networking. In this everyday world of business and fellowship, knowledge and know-how seamlessly co-existed. So did production and consumption, as constructive elements of exchange whereby people creatively interacted for personal profit and interpersonal pleasure.

But this confluence is precisely what was seen as posing a threat. During the court case that sought to interpret a shopping expedition as part of a plot to assassinate King George III, guilt or innocence was made to hinge on a separation between social orders as well as between philosophical curiosity and treasonable, mechanical know-how. Was a prime suspect actually a gentleman who could be trusted? Was his involvement motivated by a simple intellectual urge or a sinister desire to put what he learned to work? Policing Great Britain and keeping it safe, it would seem, involved more than uncovering individual plots. More fundamentally, it required a system of surveillance that sorted out the mangle of skills by which even the most ordinary citizens constructed their affairs, according to hierarchical categories that assured the proper management of both industry and ideas.

[5] On the revolutionary Atlantic, see Peter Linebaugh and Marcus Rediker, *The many-headed hydra: sailors, slaves, commoners and the hidden history of the revolutionary Atlantic* (Boston: Beacon Press, 2000).

Histories of the chemical revolution, as noted, have revised the image celebrated by Venel and the *Encyclopédie* by distinguishing between chemistry as a theoretical science/scientific discipline and as a mechanical art, building their historical narratives accordingly. So too have they reconstructed the geography of eighteenth-century chemistry by associating France with Lavoisier's glorious revolution and Germany with the material stimulation of its mining and metallurgical concerns and the philosophical burden of phlogiston. Ursula Klein's essay introduces us to a rather different landscape, one in which pharmaceutical 'art' and academic chemistry inhabited extensively overlapping material cultures. It was this virtually unified geography of laboratory-based skill that afforded so much interaction between these two institutionally separated professions and accounted for the widespread presence of hybrid apothecary-chemists, not only in Germany, but throughout eighteenth-century Europe. (We already met the prime French example of Rouelle.) As Klein puts it,

> [t]he similarity of the material culture and techniques of manufacture in eighteenth-century pharmaceutical art to the material culture and experimental techniques of academic chemistry enabled apothecaries to shift their activities smoothly from pharmaceutical manufacture to the chemical investigation of nature, or to perform chemical analyses alongside pharmaceutical manufacture. Likewise, it enabled chemists performing experiments at academic chemistry laboratories to shift from inquiries into nature to pharmacy and other technological inquiries.

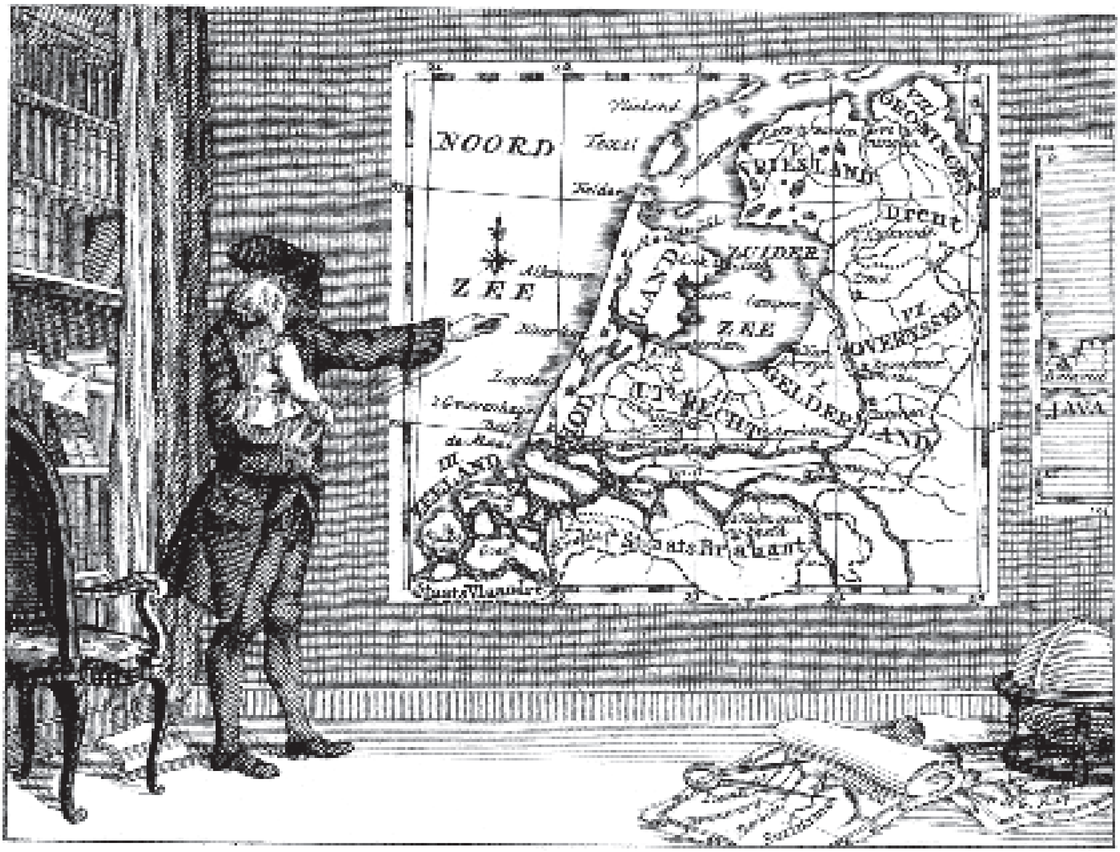
By delineating the geography of skill that practically shaped the material cultures of eighteenth century chemistry, Klein lays bare the collaboration among various forms of dexterity – manual, mental, instrumental and sentient – that marked its equally hybrid processes of material and knowledge production. The resulting picture is a healthy contrast to the traditional image of historical development shaped by an emphasis on the mathematising urges of disciplines such as astronomy. But if Klein's essay provides lessons about how to interpret the relations between pharmaceutical and academic chemistry during the eighteenth century, it also offers a key for mapping the industrialisation of chemical manufacture during the nineteenth-century. Rather than speak of a revolution, Klein describes early nineteenth-century factories as sites of transition where extant practices were expanded and existent laboratory apparatus multiplied rather than being replaced.

In an age made rich and dangerous by the trials and tribulations of sea travel, dockyards were pre-eminent nodes in some of the eighteenth century's most critical and controversial geographies of skill. Simon Schaffer's essay analyses the struggles to establish authority over British yards that hinged, similar to the court case discussed here by Jim Bennett, on the reconfiguration of shipbuilding's productive map of knowledge and know-how. Reason proved less an intrinsic attribute of productive work in this struggle, than an alternatively coercive and defensive tool of management and control.

If we return to the *Encyclopédie*, we find the anonymous author of its article on shipbuilding (*vaisseaux, marine*) stressing experience as the sole source of both the mathematical rules of proportion that governed it and the practical wisdom that shaped constructive modifications. Through time, he recounted, shipwrights had learned to mediate between the laws of fixed mathematical proportion – laws of their own invention – and recognition of the unique parameters inherent in a ship's various requirements. A ship had to meet general structural imperatives. So too must it handle the individual challenges of both nature (storms, high seas and so forth) and human demand (heavy cargo, the necessities of war and defence, etc.). Here we see a clear case of cunning, practical intelligence (the heritage of *metis*) seeking to tame ambient irregularities – both the complexly changing realities of nature and human society – and transform experience into a productive system of skilful knowledge and know-how.

If shipwrights thus had reasons of their own, however, so did the late eighteenth-century British functionaries and their philosophical allies who sought to make efficiency rule the waves. These men endeavoured to institute a mechanical system in which dockyard practices were interpreted as rote activities in need of external organisation and dock workers as so many automata given purpose and direction by the superior science of their managers. In a previous publication on enlightened automata, Schaffer reminds us that this is how Marx came to characterise manufacture in general: as a system in which workers 'are cast merely as its conscious linkages'. Polemically and managerially shorn of their ability to reason, workers were left with nothing but the province of mechanical labour. Retrospectively, it came to seem 'as if most subjects had never been, could perhaps never be, enlightened'. By putting 'highly charged words' such as reason, theory and experiment 'back in the places where politicised languages of art and practice provided their peculiarly forceful sense,' Schaffer here shows how Enlightenment reform could yield such a new geography of skill in which the co-ordinates of scientific reason corresponded to those of social and managerial control. [6]

[6] Karl Marx, *Grundrisse*, Martin Nicolaus, ed. (Harmondsworth: Penguin Books, 1976), p. 692; Simon Schaffer, 'Enlightened automata,' William Clark, Jan Golinski and Simon Schaffer, eds., *The sciences in enlightened Europe* (Chicago: University of Chicago Press, 1999), pp. 126-165. See p. 164.



Neêrland is uw Vaderland. Veilig woont ge 'er in.
Als gy groot zyt, hebt gy dáár ook uw huisgezin.

'The Netherland is your fatherland. You live there safely. When you grow up, you'll raise your family there too.'
The letter 'N' from a patriotic ABC book for Dutch children: W. Holtrop, *Vaderlandsch A – B boek voor de nederlandsche jeugd* (Amsterdam, 1781). Courtesy of Atlas van Stolk, Rotterdam.

ILLUSTRATION 23

Mapping steam engines and skill in eighteenth-century Holland

Lissa Roberts

If we were to draw a map of skill, how would it look? How would that map capture the ways that skills travel across both space *and* time? How would we depict our map's subject, given that 'skill' exists only in embodied form – in the person or apparatus that exercises it, the product or effect to which its exercise gives rise? And how would we map its subsequent traces – the routes along which producers, audiences and consumers interpret and valorise its various embodiments and effects? This essay attempts such a map, largely drawn in words rather than abstract co-ordinates and images.

The constellation of embodied skills, their deployments and traces that form the subject of this essay comes from the early history of steam power in the Netherlands. Of interest to us are four Dutch sites that saw the introduction of steam apparatus – aeolipiles, steam pumps and engines – during the eighteenth century. Not only do they join to form a revealing portrait of steam technology's early development outside England, the usual context in which historians set the story's paradigmatic contours. They also afford the analysis of a set of apparatus as the site of skill's multi-faceted character. By this I mean to point to the matrix of mentally and manually dextrous work that constructed them, on one hand, and the equally complicated weave of the various functions they served and meanings attributed to them, on the other.

We begin with steam technology's first documented appearance in the Netherlands, in 1716, when a now completely unknown Dutch entrepreneur requested and obtained a patent from the Estates of Holland for what seems to have been a Savery-type steam pump.[1] Strikingly, he nowhere mentioned England in his patent application and the uses to which he would put his invention were drainage and the construction of garden fountains – far removed

[1] Without a sketch or proper description, we cannot be sure about whether the design of this machine followed that of Thomas Savery or not. Here I mention the highly speculative claim of Jan Verbruggen, whose years of historical study of early steam engines dovetailed his career as an engineer. See Jan Verbruggen, *The correspondence of Jan Daniël Huichelbos van Liender with James Watt* (PhD dissertation, University of Twente, 2005), p. 10.

from the coal mines of England and most history books. At virtually the same time that steam technology was thereby first introduced to the Dutch countryside, a young Willem 's Gravesande was in London as part of a diplomatic mission. His secretarial duties left him enough spare time to investigate steam technology collaboratively with the Royal Society demonstrator John Theophile Desaguliers. 's Gravesande 's subsequent discussions of steam in his Leiden University lectures and the pages of his *Mathematical elements of physics confirmed by experiments, or an introduction to Newtonian philosophy* bring us to the second site of this essay's investigation, Leiden University's physics theatre.

We move from the academic centre of Leiden University to the bustling port of Rotterdam for this essay's third site. Here we meet a group of entrepreneurial amateurs who formed the *Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte* (Batavian Society for Experimental Philosophy) in 1770 with the express purpose of stimulating the use of steam power for the all-important task of water management. From the urban activities of Rotterdam, we travel to the Arcadian fields of rural Kennemerland, south of Haarlem, for our fourth site. Here, on the estate of a wealthy Dutch banker turned art connoisseur and country gentleman, steam made its appearance in the form of the first fully Dutch designed and constructed (Newcomen-type) steam engine in 1781. Far from serving as the harbinger of a denaturalising and socially dislocating industrial revolution, this machine became a symbol of the efforts by which Dutch Patriots hoped to sew the hybrids seeds of moral and material regeneration at the end of the long eighteenth century.

The machine in the garden

In September of 1716 the Estates of Holland granted Jacob van Briemen, citizen of The Hague, a patent that gave him the exclusive right to harness steam power for pumping water out of canals, pits and wells, and for operating garden fountains, cascades, and other water works. Van Briemen opened his application with a claim of his machine's historical importance – it answered a centuries-old struggle to raise great quantities of water. He then went on to stress how long and hard he had worked, and what great expense he had borne to perfect his apparatus. The machine itself was described as powerful, capable of performing wonders and creating beauty. At the same time Van Briemen was careful to point out its economy of size and price. For all the work it was capable of performing, he explained, it took up very little space, was totally portable and cost very little to set up, move and maintain. We can detect a number of qualitative calibrations at work here: the machine's power to create, its portability and economy. As the historian Christine MacLeod has pointed out, this form of description in patent applications would be replaced in the nineteenth century by standardised, quantitative measurements of power such as horsepower.[2]

We find very little in the way of actual technical description in Van Briemen's application, but he did note that his machine was similar to what one might find abroad, especially in the gardens of France. He thereby gave his invention extra allure by situating it in a highly fashionable tradition, that of formal garden design. He also left an intriguing trace of mysterious presences and absences that need to be followed if we are to understand the early history of steam technology. Van Briemen started working on his machine around 1699, shortly after Thomas Savery received a patent for his steam pump in England. If Van Briemen borrowed elements of his design from Savery, why did he not mention the connection? Why compare his invention to machines one found in French gardens? And just where were all these French machines to which he referred? Were they also Savery-type pumps or descendants of designs first published in Salomon de Caus' influential book *Les raisons des forces mouvantes* of 1615? By what route did the necessary knowledge and skills come together for Van Briemen to flash so briefly across the stage of history?

Whatever the answers to these questions, those who granted Van Briemen a patent seem to have agreed that his invention should be treated strictly as a commercial issue. He requested a broad-ranging monopoly for the application of steam to raising water and they responded, not by demanding specifications of the apparatus' structure, but by agreeing to an expansive description of its field of possible application and specifying the fine interlopers would have to pay Van Briemen for encroaching on his monopoly.

The steam engine as a demonstration device

At about the same time that Van Briemen was applying for a patent, Willem 's Gravesande was in London as secretary to a Dutch diplomatic mission. In his spare time he attended meetings of the Royal Society where he got to know the society's demonstrator John Theophile Desaguliers quite well. As Desaguliers later recorded in his book *A course on experimental philosophy*, the two collaborated on a number of projects, including work to improve Thomas Savery's steam engine design.[3] Thanks to the contacts 's Gravesande made in London

[2] For full documentation of Van Briemen's patent application, see 'Machine tot het opvoeren van water door vuur,' Nederlands Nationaal Archief, Archive collection Staten van Holland (archive #3515), inventaris #1668, September 1716. For the history of patent descriptions, see Christine MacLeod, *Inventing the Industrial Revolution* (Cambridge: Cambridge University Press, 1988).

[3] John Theophile Desaguliers, *A course on experimental philosophy*, 3rd edition (London, 1743), pp. 485-488.

– both diplomatic and philosophical – he was recommended for a vacant professorship at the University of Leiden. But, before fully ensconcing himself in the position that would bring him international fame, 's Gravesande travelled to Hesse-Kassel in 1721 where he advised the Landgrave on various technical schemes. This led him to make the acquaintance of two highly placed architects with whom he signed a contract to design and market steam engines – this time, modified Newcomen engines – for the explicitly stated purposes of land drainage and powering garden fountains.[4] This practical experience notwithstanding, 's Gravesande's historical reputation derives primarily from his Leiden period where he lectured on experimental physics at Leiden University and published his classic work *Mathematical elements of physics confirmed by experiments*, *or an introduction to newtonian philosophy*. 's Gravesande maintained an interest in steam both in class and in print, but his treatment in these two contexts differed considerably from the practical field of entrepreneurial engineering. In his book we find him presenting steam in the theoretical context of heat's expansive effects and its ability to change a body's state from solid to liquid. Referring the action of heat on bodies to the play between attractive and repulsive forces, he ended his discussion with the statement that a body's elasticity increases with the augmentation of heat, sometimes to the point of total vaporisation.[5]

He followed this up in his book with two experiments, the apparatus for which are illustrated in the book. The first, which simply demonstrates the expansive effect of heat on water, involves heating an aeolipile – a stripped down version of the machine De Caus and other early steam pioneers used to send water jets shooting out of decorative fountains. The second so-called 'experiment' was actually a playful demonstration that we might expect to see performed in a salon or popular lecture hall, meant as much to entertain as to edify. A water-filled aeolipile is attached to a cart with four wheels. So long as it remains closed while being heated, pressure builds inside the ball. Opening the sphere reduces the pressure on one side, the steam escapes and the cart is propelled forward.

As professor of experimental physics, 's Gravesande oversaw Leiden University's physics cabinet that housed the demonstration devices he used in his lectures and described in his publications. Established in 1675, the collection took a new turn when 's Gravesande chose to include models of working machines alongside experimental instruments. Together these devices – that is,

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[4] For details see Lissa Roberts, 'An Arcadian apparatus: the introduction of the steam engine into the Dutch landscape,' *Technology and culture* 45 (2004): 251-276, especially pp. 256-257.

[5] Willem 's Gravesande, *Physices elementa mathematica experimentis confirmata. Sive introductio ad philsophiam newtonianam* (Leiden, 1720-1721).

instruments and machine models – were used to demonstrate the physical principles that gave witness to the orderly working of divine creation while celebrating the creativity and ingenuity with which nature could be harnessed for human benefit. The collection pointed, in other words, simultaneously to the worlds of theory and practice, tying them together with the multi-faceted concept of utility.[6]

’s Gravesande bore these twin purposes in mind when he ordered a model steam engine for the collection in 1727. His theoretical discussion of steam phenomena is described above. Strikingly, he justified the inclusion of a model engine in the university’s physics cabinet in quite another way, stating that its purpose was to demonstrate ‘in miniature… how, through the means of fire, water can be pumped out of deep mines or from inundated fields with greater success than by any mills’.[7] Ultimately, ’s Gravesande ’s very practical hope was that steam engines would replace windmills as the driving force behind the Netherlands’ constant battle to preserve its landscape from inundation.

Why should ’s Gravesande have chosen to introduce such practical issues into his requests for funding and his curriculum? What made the University of Leiden an appropriate place for such concerns? To begin, Dutch universities and a number of the professors who worked there in the eighteenth century did not limit themselves to the world of scholarship. Perhaps related to the fact that the Netherlands lacked a national academy upon which governmental agencies could call for advice and research, Dutch universities had long included an element of practical learning in their character. Alongside promoting and pursuing academic scholarship, universities and their faculty members took part in a double tradition of public service and useful application. Professors were frequently called upon to advise local and provincial governments as well as trading companies such as the Dutch East Indies Company on matters ranging from health to navigation and engineering. At the university itself, their teaching duties included topics such as surveying, civil engineering, fortification building and hydraulics. In the medical faculty, professors such as Herman Boerhaave championed clinical teaching at the bedside of sick patients, taught practical botany and included chemical experiments in their chemistry courses.[8]

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[6] On the multi-faceted definition and role of utility in the Dutch Enlightenment, see Lissa Roberts, ‘Going Dutch: situating science in the Dutch enlightenment,’ William Clark, Jan Golinski and Simon Schaffer, eds., *The sciences in enlightened Europe* (Chicago: University of Chicago Press, 1999), pp. 350-388.

[7] ‘…in het klein…hoe door middel van het vuur het waeter uyt diepe mynen off geinondeerde plaetsen met beter succes als door eenige molens kan werden omhoog gedreven…’ ’s Gravesande to university trustees, 6 February 1727, University of Leiden Universiteitsbibliotheek, Archief van curatoren van de Leidse Universiteit, vol. 1 (1574-1815).

[8] C.A. Davids, ‘Universiteiten, illustre scholen en de verspreiding van technische kennis in Nederland, eind 16e – begin 19e eeuw,’ *Batavia academica* VIII (1990): 3-34.

One can see a counterpart to this combined focus on intellectual and practical work in the orientation of Leiden's student population and the courses of study they chose to follow. The University of Leiden allowed for a level of academic freedom unknown at many other European universities. In place of the traditional insistence that students matriculate in the Arts Faculty before continuing on to the study of medicine, law or theology, students at Leiden were allowed to construct their own course of study – taking Arts courses as they pleased. This meant that a wide variety of students might follow a course in experimental physics because of interest rather than compulsion. There were those who would go on to earn a living as instrument makers and engineers, who were interested to learn how nature might be calibrated and put to work. Others recognised the cultural capital to be earned by being at least superficially conversant with the workings of nature. Still others were keen to apply what they learned about both the regularity and peculiarities of nature to their study of theology, moral philosophy or medicine. Finally, sons of the country's elite who would one day take their fathers' places as governors of trading syndicates like the Dutch East Indies Company, or as members of water management boards and government committees, might generally choose to take degrees in law, but familiarity with both nature and machines at work prepared them for a myriad of decisions they would later have to make or oversee. Should ships be outfitted with a new kind of rudder? What was the best method for cleansing urban canals and dredging waterways? Should peat exploitation be allowed on a particular parcel of land? These were the kinds of questions that the Netherlands' governing elite had to face as part of their careers.

Returning to the question of including machine models in the physics cabinet at Leiden University, a few words about the cognitive implications of this move are in order.[9] Leiden University's physics theatre was originally established in answer to its first professor, Burchardus de Volder's request to show by experimental display 'the truth and certainty of the postulates presented to students in *Physica theoretica*'.[10] Active demonstrations had a different impact on their audiences, he argued, than did reading a book on the same subject. Demonstrations brought phenomena to life, so to speak, and engaged observers' senses in addition to their literary imaginations. De Volder had experienced this himself in London, where he visited the Royal Society in 1674; he viewed

[9] Attention has only recently been given to the role of three dimensional models in science. See Soraya de Chadarevian and Nick Hopwood, eds., *Models: the third dimension of science* (Stanford: Standford University Press, 2004) and my review of the book in *Technology and culture* 47 (2006): 268-270.
[10] Governors' Resolutions December 3, 1674, Molhuysen, vol. 3, p. 298; quoted in Peter de Clercq, *The Leiden cabinet of physics* (Leiden: Museum Boerhaave, 1989), p.5.

Leiden University's newly established physics theatre as a venue for transforming experimental philosophy into a pedagogical program.[11] Scholasticism would be vanquished, appropriately enough, by deed instead of word.

This required stocking the physics theatre with the necessary equipment for carrying out demonstrations, including what came to be referred to as 'philosophical instruments'; that is, instruments such as air pumps that 'exhibit[ed] the operations of nature'. As mentioned above, 's Gravesande expanded the collection to include scale models of working machines. Housed together in a single cabinet, these apparatus were all intended to serve a pedagogical purpose, and can therefore be classed as didactic instruments.[12] But what does their physical presence in the same collection and their classification under a single rubric of didactic display reveal in terms of the set of pedagogical purposes and imperatives they embodied?

Cognitively speaking, philosophical instruments and machine models function somewhat differently from each other. In his discussion of Michael Faraday's public demonstrations in the nineteenth century, the philosopher David Gooding describes Faraday's demonstration instruments as the vehicles whereby students could be transported from the lecture hall to 'nature's school'.[13] That is, through Faraday's accomplished construction and manipulation of instruments, he made it appear as though observers were witnessing natural processes at work, revealed and yet unhindered by their artifactual production. What can we say, along these lines, about machine models? Did they cognitively transport students from the lecture hall either to 'nature's school' or, analogously, to the field of engineering practice? What was required for them to do this successfully?

Gooding and others have noted that demonstration instruments are most successful in displaying 'nature at work' when their active presence is the least apparent. That is, their pedagogical worth and the skill of the demonstrator who deploys them are dependent on the ability to make their manipulation

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[11] It is interesting to note that De Volder identified the reliance on demonstration that he witnessed at the Royal Society with Cartesianism. In 1674 he commented, 'que la Philosophie de Descartes étoit estimée, en toutes sortes de Gouvernemens, comme en France et Angleterre, où la Societé Royale étoit établie sur les fondemens du Cartesianisme…' Quoted in Jean Le Clerc, 'Éloge de feu de Mr. De Volder Professeur en Philosophie et aux Mathematiques, dan l'Academie de Leide,' *Bibliothèque choisi* 18 (1709): 346-401. See p. 357.

[12] Quotation taken from Joseph Priestley, *The history and present state of electricity, with original experiments*, 3rd edition, 2 vols. (London, 1775), vol. 1, xxi. For the concept of 'didactic instruments' see Willem Hackmann, 'Scientific instruments: models of brass and aids to discovery,' David Gooding, Trevor Pinch and Simon Schaffer, eds. *The uses of experiment* (Cambridge: Cambridge University Press, 1989), pp. 31-65, p. 43.

[13] David Gooding, "In nature's school': Faraday as an experimentalist,' in David Gooding and Frank James, eds., *Faraday rediscovered* (New York: Macmillan, 1985), pp. 104-135.

of phenomena transparent. As the demonstration in question proceeds, the instrument's productive presence must recede from the attention of their audience, which is riveted instead on the 'natural' phenomena that the instruments' directed activity manufacture. The reputation of scientific demonstrators such as Desaguliers in the eighteenth century and Faraday in the nineteenth, rested in good part on their genius for constructing devices and publicly using them (often after long, gruelling rehearsals) in just this way.[14]

It was not always desirable, on the other hand, for machine models to fade into practical transparency. For if they encased natural phenomena, as when 's Gravesande's demonstrations highlighted the expansive power of steam, so too were they meant to pay homage to the history and potential of man's inventive genius. In order to do this, their presence had to remain visible. How else could they represent – indeed, celebrate – the ways in which human intervention purposefully transformed the environment in which it was set?

There appears, then, to be some cognitive distance between these two subcategories of didactic instruments. The didactic success of the one depended on its fading into an apparent state of phenomenological absence. The other had to remain artifactually present throughout the demonstration of its function. We can explain this distance as a rather obvious reflection of the fact that philosophical instruments were intended to illustrate general laws of nature – the law of free fall, the necessary presence of air to support life, etc. – while machine models replicated specific instances of the application of mechanical principles. Endeavouring to replicate natural processes – that is, entering 'nature's school' – entailed developing a set of sensibilities and skills, both on the part of the instrument maker and on the part of the demonstrator, that differed from those needed to invoke instances of technological virtuosity with machine models.

If we label this set of distinctions between philosophical instruments and machine models 'cognitive diversity', we can go on to see that, in fact, diversity actually extended much farther. The pedagogical potential of each apparatus was unique, characterised by the confluence of a number of factors: the function it was supposed to perform, the principles or design it was supposed to represent or replicate, its level of technological complexity and sophistication, the physical laws that governed its ability to function, its operational reliability and the audience before whom it was to be operated. Thus, 's Gravesande 's

[14] See Simon Schaffer, 'Glass works: Newton's prisms and the uses of experiment,' David Gooding, Trevor Pinch and Simon Schaffer, eds., *The uses of experiment. Studies in the natural sciences* (Cambridge: Cambridge University Press, 1989), pp. 67-104 for an interesting discussion of how Newton's initially controversial, experimental use of prisms gained transparency.

‘fall apparatus’ was a beautifully simple device that demonstrated the force of a falling body’s impact by allowing for a precise measurement of the impression left in soft clay when a ball landed on it after being dropped from one of four pre-determined heights. His magic lantern, in contrast, demonstrated the effects of light dispersion in a striking but only vaguely edifying way; the relation between the expansive image of a pastoral landscape or a devilish monster and the mathematical laws that described their projection were clarified only in the most qualitatively general way.[15]

When we focus on machine models such as model steam engines, this difference needs to be specified even further because of a basic problem encountered in the material world: the problem of scale. Thanks to the Galilean-Newtonian synthesis, small-scale experimental demonstrations can be taken to represent nature at large; whether little or big, bodies are understood to fall according to a constant law. The same bodies, however, heat up and cool down at different rates of time, depending on their size – a fact known at Leiden since at least Boerhaave’s experimental work in the 1720’s. Small-scale model steam engines, therefore, cannot be taken as precise blueprints for their large-scale counterparts, as ’s Gravesande ’s successor Jean Nicolas Sebastian Allamand had to confront in a rather costly way.

In 1772 Allamand ordered an expensive and beautiful model of a Newcomen engine from the London instrument maker Edward Nairne for the university’s physics cabinet.[16] Nairne’s model copied the design of large-scale machines in miniature with artistic precision. Its small size, however, caused its cylinder to cool down so rapidly that it ran out of steam after only a few strokes. This was hardly enough to demonstrate the intricacies of how the machine operated, let alone evoke the image of a constantly working steam engine in the field. It was lovely to look at, but a didactic failure.[17]

To solve this pedagogical problem, Allamand turned to the Leiden instrument maker Jan Paauw, who provided an equally expensive, but much larger, replacement. Paauw belonged to a small but notable group in the Netherlands who made their living by combining remarkable manual dexterity with a publicly recognised degree of learning. It was in this sense as much as in terms of

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[15] For an illustration and description of ’s Gravesande’s fall instrument, see Peter de Clercq, *The Leiden cabinet*, pp. 28-29. For his magic lantern, see idem., *Het koperen kabinet: schatkamers van de wetenschap, 1550-1950* (Leiden: Museum Boerhaave, 1994), p. 33.

[16] Nairne based his model on one of the Chelsea Waterworks engines built in 1741-1742 to replace tide-driven pumps that provided water to Westminster. See Johannes Luchtmans, *Reis naar Engeland in 1772*, ed. Paul Hoftijzer and Jos van Waterschoot (Leiden: Burgersdijk and Niermans Publishers, 1995), p. 35. I thank Peter de Clercq for this citation.

[17] The problem of scale and complicated relation between models and the full-scale objects they are supposed to represent is also examined by Simon Schaffer’s essay in this volume.

clientele that he followed in the footsteps of the famous Van Musschenbroek family of instrument-makers.[18]

Having himself graduated from Leiden University, Paauw was in a position to think about scientific instruments, including the steam engine, in a number of coexisting ways. First, as he had learned in lectures at the university physics theatre, mechanical devices embodied physical principles in a demonstrable way. Second, as a student he must also have observed that instruments and demonstration devices could be technically fascinating in their own right. Third, Paauw had the acquired wisdom to grasp the practical significance of the instruments he observed and constructed. And, putting these points together, he could assess such devices in terms of their potential commercial value. This meant that he could be counted on, for commercial, practical and intellectual reasons, to deliver a model engine that met the various requirements it was intended to satisfy.

And yet, though this model promised to demonstrate the mechanical actions of a steam engine with reliable longevity, making it both a superior didactic instrument and a vivid advertisement for the applied power of steam, it too was a model in only a limited sense. First, the problem of scale meant that modifications would have to be made if one wanted to scale up to a full size working steam engine. Second, the wide array of uses to which a steam engine could be put practically – powering garden fountains, pumping water from mine shafts, draining inundated lands – and the specific technological demands that each construction site entailed, could never be exhaustively captured in a single model. Without familiarity with local constraints and the practically gained knowledge needed to realise required modifications, a single model would never suffice to map out the successful building and operation of a working steam engine. That set of skills could only be acquired through years of practical experience.

With all this said, however, we must recognise that Leiden University's physics cabinet was not maintained for the purpose of educating an army of engineers (in contrast to the French engineering *écoles*), just as it was not its mission to help turn out a cadre of professional physicists. Rather, its admittedly dilettantish character was moulded by the educational interests and needs of the university's students and the culturally sanctioned image and position of the university in general. This is ultimately what lent the physics cabinet its unified character and helped its professors decide which demonstration devices to purchase and how to use them.

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[18] On the Van Musschenbroek family, see Peter de Clercq, *At the sign of the Oriental Lamp. The Musschenbroek workshop in Leiden, 1660-1750* (Rotterdam: Erasmus Publishing, 1997). On Paauw, see Maria Rooseboom, *Bijdrage tot de geschiedenis der instrumentmakerskunst in de noordelijke Nederlanden tot omstreeks 1840* (Leiden: Rijksmuseum voor de Geschiedenis der Natuurwetenschappen, 1950), pp. 111-112.

Leiden University's physics cabinet served as a sort of three-dimensional encyclopaedia, a materialised counterpart to Diderot and d'Alembert's great publishing endeavour in the sense that it brought together the work of the hand and mind to present a compendium of state-of-the-art knowledge. The cabinet's contents were used to stimulate an appreciation of nature's laws, while simultaneously promoting respect for the practical expertise of engineers and craftsmen and making manifest the relations between their inventions and the physical principles by which they worked. As such, the physics cabinet realised an expressly Enlightenment project. But, just as the Enlightenment was a European-wide movement with important regional variations, so was it the case that Leiden University's physics cabinet took on different contours than did its book-bound counterpart in France. Diderot advertised the *Encyclopédie* as a subversive weapon directed against the status quo, a claim taken quite seriously by French censors. Leiden University and its physics theatre, on the other hand, were stalwart components of Dutch society. Rather than challenging the official culture around them, they represented and helped maintain it by educating those who formed and served its dominant classes. If the key Enlightenment concept of utility suffered from a kind of cultural schizophrenia in France – one manifestation promoted by its centralising government, another by it critics – it was embraced in the Netherlands as a way of bringing together various interests to create a greater whole.[19]

The world of private initiative: promotion of steam in Rotterdam

If communicating about steam engines with scale models ultimately served a culturally determined set of purposes in Leiden, what can we say about the deployment of their full-size counterparts? In 1770 a group of concerned citizens and scientific amateurs were granted a government charter enabling them to found the *Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte te Rotterdam* (The Batavian Society for Experimental Philosophy of Rotterdam). While its written constitution organised the society along rather typical lines – regular meetings with lectures and demonstrations, essay contests and a journal – the purpose behind the society's establishment was rather unique. Steven Hoogendijk, who financially backed the society, and his colleagues were motivated by a missionary desire to promote the adoption of steam engines in the Netherlands. Long involved in the practical world of water management and land drainage, Hoogendijk was convinced that steam rather than wind power was the Netherlands' best hope. If men like Jacob van Briemen had sought to

[19] Lissa Roberts, 'Devices without borders: what an eighteenth-century display of steam engines can teach us about 'public' and 'popular' science,' *Science and education* 16 (2007): 561-572.

place steam powered machines in the gardens of paying customers, Hoogendijk and his fellow society members hoped to place them in the Dutch national garden as a way to protect the integrity of its landscape.[20]

Hoogendijk's own experience with municipal water management went back at least to 1745 when the municipality of Rotterdam hired him to supervise a windmill that powered the flushing of its canals – a quite necessary function given that the canals served a multitude of purposes, including that of a municipal sewage system. Based on his subsequent experience with the periodic inadequacies of wind power for the purpose of water management, his reading of authors such as Desaguliers and discussions with men such as the engineer John Smeaton during his visit to the Netherlands in 1755, Hoogendijk began advocating the adoption of steam to Rotterdam municipal officials at least by 1757.[21] The municipal government responded by sending its reclamation inspector and windmill builder Maarten Waltman to London to observe the Thames waterworks project where a Savery pump helped provide water to the city. Ignorant of English, Waltman took a city notary along on the tour.

Neither returned with a positive impression of what they had seen, which later commentators have attributed to their technical ignorance. We might, however, see it as reflecting the context-bound nature of skill. Waltman clearly did not report the technical specifications of the engine he observed with full accuracy – perhaps, indeed, he was not schooled enough to do so. This was the contention of Hoogendijk and subsequent analysts who considered steam a superior power source. But, Waltman made his living by building windmills and inspecting reclamation work. While this might have biased him in favour of the kind of technology upon which his living depended, it also afforded him hard-won insight regarding the efficacy of water management systems as a whole. The facts that 'one or two men ha[d] to be present day and night' to stoke the engine's fire, that the engine had to be cleaned every five weeks and that every (minor) repair necessitated the entire machine be stopped did not strike Waltman as a promise of efficiency. His negative judgement rested, then, on his consideration of the steam engine's ability to function in Rotterdam.[22]

With this report on the table, both Hoogendijk and Rotterdam chose to let the matter lie for a number of years. Public pressure from the *Bataafsch Genootschap* in the 1770s brought the issue back to life. The society adopted a

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[20] On the Netherlands as a garden, see Alette Fleischer's essay in the second section of this volume.

[21] Kees van der Pols and Jan Verbruggen, *Stoombemaling in Nederland/Steam drainage in the Netherlands, 1770-1870* (Delft: Delft University Press, 1996), p. 25; John Smeaton, *Journey to the Low Countries, 1755* (London: Courier Press, 1938).

[22] Waltman's report is reprinted with commentary in Kees van der Pols and Jan Verbruggen, *Stoombemaling*, pp. 150-157.

two-pronged approach to achieve their end. First and quite typical for an eighteenth-century amateur society, demonstration lectures were held so that members could gain familiarity with steam engines, very much in the way that 's Gravesande had done in Leiden. In fact, it was his successor Allamand who brought a model engine to the *Bataafsch Genootschap* and lectured to its members as early as 1772. Further, and also quite typical, essay contests were held to encourage innovative members of the public to improve steam engine design and adapt the apparatus to Dutch needs. Winning entries were published in the society's journal. In the year 1800 an entire edition of the journal was dedicated to reviewing the history of steam engines in the Netherlands and stimulating its extended use in the future; the society's active role in this history was prominently displayed.[23]

The second track involved the active promotion and financing of full-scale projects in which steam engines could be showcased as superior water-management tools. The first such endeavour entailed constructing a steam engine on the outskirts of Rotterdam to help regulate the flow of water in the city's canals. In 1771, the *Bataafsch Genootschap* asked the municipality for permission to erect a steam pumping station in an abandoned gunpowder magazine near Rotterdam's East Gate (Oostpoort). Following initial rejection and extended negotiations (which also demanded considerable skill), permission was granted in 1774.[24]

This was a highly complex undertaking, not only for technological reasons – the steam engine would have to contend with highly fluctuating water levels – but for bureaucratic reason as well. Rotterdam's canals were part of a larger system that connected them to the surrounding polders and placed their regulation at least partially under the jurisdiction of the Schieland *hoogheemraadschap* (the regional water management board). While urban interests called for higher water levels in the summer to combat stagnancy, stench and pollution, and lower levels during the rainy seasons to combat flooding, agricultural and safety needs in the surrounding polders threatened to reverse this order. The Rotte River served both as a reservoir for the polders and as an outlet for Rotterdam's canals. Its own periodically excess water could – in principle – be discharged into the larger Maas River, but officials only allowed this if the Maas was sufficiently low and the winds were strong enough to power the necessary pumping apparatus. This left Rotterdam at the mercy of nature and bureaucratic oversight – neither of which could be counted on for sympathy.

23 Lambertus Bicker, 'Historie der vuurmachines,' *Nieuwe verhandelingen van het Bataafsch Genootschap* I (1800): 1-132.

24 For (technical) details of the project, see Kees van der Pols and Jan Verbruggen, *Stoombemaling*, pp. 30-37 and Jan Verbruggen, *The correspondence of Jan Daniël Huichelbos van Liender*, pp. 12-18.

City boosters such as Hoogendijk looked for a 'technological fix' to overcome the dependence of their city's canals on this combined bureaucratic and natural system. With the erection of a steam engine, they hoped to power an alternative discharge scheme.

This involved both adjusting the installation to local environmental conditions and a complex process of negotiating with layers of interested parties that included the local government officials of Rotterdam, the governors of the Schieland water management board and the land owners whose livelihoods depended on the regulation of water. Why should any of these groups place their trust in novel and as yet unproven technology? As was so often remarked, wind power was free if not always available when needed, and windmills were a tried-and-true feature of the Dutch landscape. Turning to steam would require investing in technology that was both expensive and temperamental. As Waltman had commented two decades before, workmen would have to be specially trained (or imported from the Netherlands' competitor England) and remain constantly on hand, both to stoke the engine's fire and to repair the delicate machinery should it break down at an inopportune moment. Finally Hoogendijk and his colleagues got the go-ahead to build, but only because they promised to take the entire financial and engineering risks on their own shoulders. Hoogendijk personally contributed a hefty 25,000 guilders to the cause.

Hoogendijk also oversaw the construction of the pumping apparatus to be powered by the engine and this is where things went wrong. The innovations required to pump water at various heights were apparently beyond his considerable engineering skills, but it mattered little to the audience of officials who came to observe the Oostpoort demonstration. Not interested *per se* in the claimed advantages of steam, they wanted an installation that did what it promised. Explaining that the engine worked well but that the complicated pumping system to which it was attached was inadequate had little effect. What they noticed was that a lot of money – though not their own! – had been spent on a project that failed. Even if the advocates of steam demonstrated mathematically that one steam engine could do the work of at least four windmills, officials responded coldly that windmills got the job done. It would be ten years before the society was given another chance.

When this chance came in 1787, the situation in and around Rotterdam was greatly complicated by the growing political polarisation between supporters of the House of Orange and their opponents who were known as Patriots, among whose ranks were a number of prominent Batavian Society members. With the passive approval of both the local polder board and the Schieland water management board – again we see the overlapping layers of governmental oversight that characterised life in a decentralised republic – the society leased a strip of private land in the Blijdorp polder (not far from Rotterdam) on which to build a steam powered pumping station for removing excess water from the polder. To get this far, they had to pay a highly inflated rent and promise to remove everything when their one-year lease expired. Installation of the first Watt engine in the Netherlands began forthwith, but in the face of loud protests from local inhabitants. Fearing that it would pollute the countryside and sterilise their cows, local residents demanded its speedy removal.

Official witnesses and visitors ranging from provincial administrators and the Dutch Inspector General of Rivers to the Stadholder Willem V and his family seem to have been less interested in politics and roundly praised the results they observed – so much so that the installation remained in service until 1791. By then, society members suggested that the local residents who benefited from the steam engine might want to take it over and pay for its maintenance. The answer they received has often been quoted. Locals shouted, 'that machine is a Patriot contraption and we will have none of it'. The Blijdorp engine was subsequently dismantled and put in storage, never to be used again.

Back to the garden

By this time, however, another steam engine had been successfully operating in the Netherlands for some ten years. Also the product of private initiative, this engine was commissioned, not by a scientific society, but by a wealthy banker and Amsterdam city official named John Hope to regulate water flow in the newly installed landscape garden that graced his country estate Groenendaal, just south of Haarlem. Hope's family, one of the wealthiest in the Netherlands, was known for its patronage of artistic and knowledge production. He and his brothers owned extensive art collections and bankrolled endeavours such as the first Dutch journal dedicated to publishing articles favourable to the 'new' chemistry.[25] A longstanding member of the *Hollandsche Maatschappij der Wetenschappen* (the Dutch Society of Science – Holland's premier scientific society), John Hope joined the *Bataafsch Genootschap* soon after its establishment in 1772. This placed him in a position to keep apprised of the society's efforts to promote the adoption of steam power in the Netherlands. It also puts a question mark after the often-made claim that Dutch steam engine promoters at the end of the eighteenth century were political radicals; the Hope family remained supporters of the House of Orange throughout the revolutionary decades that brought the long century to a close.[26]

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[25] *Recherches physico-chimiques* (Amsterdam, 1792-1794).

[26] For an example of this mistaken view of the Netherlands, see Margaret Jacob, *Scientific culture and the making of the industrial West* (Oxford: Oxford University Press, 1997), pp. 150-152.

As recently uncovered letters between Hope, Matthew Boulton and James Watt show, Hope did more than simply keep abreast of the society's activities. It was he who took the initiative to suggest that Boulton and Watt develop a steam-powered drainage plan for the dangerously looming Haarlemmer Lake, which periodically threatened an area extending from Leiden to Amsterdam with inundation.[27] Toward this end, he had maps of the lake forwarded to Boulton. He also discussed the possibility of constructing a steam engine on his country estate as a way to demonstrate its practical value for water management. Hope was at the time busy with transforming the extensive grounds of his estate into an English-style landscape park. He had already installed a windmill to manage the flow of water that was to meander through his park; a steam engine wasn't necessary, but Hope thought this, nonetheless, a good opportunity to advertise its potential.[28]

Aware of technological difficulties, as well as the simultaneous need to satisfy customers and maintain a good reputation, Watt responded politely but with great caution.

> Such an engine would be so trifling and its parts so small that they would be very subject to go out of order and would require very nice workmen to put them in order again and as it would have more friction than a larger, would neither give you the satisfaction you require, nor do our invention justice as we should be obliged to alter many of the parts to fit them to its size, besides it would not cost your £50 less than the (large) one.[29]

We find Watt confronting the problem of scale here, but not only as a physical issue (increasing friction). Small might be beautiful, but it made both construction and maintenance more problematic. Further, costs did not decrease proportional to size, though Watt and Boulton's reputation might very well do so.

The project also raised the question of legal rights, which Watt and Boulton showed themselves keen to protect. Without a patent that was valid throughout the United Provinces, Watt informed Hope, they would not be willing to export their technology. If this were to be granted (no doubt through hoped-for intervention by Hope himself), they would be much more willing to work for him at a favourable rate.

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27 This undertaking was so immense and involved so many conflicting interests that it was not finally tackled until the middle of the nineteenth century. See Kees van der Pols and Jan Verbruggen, *Stoombemaling*, pp. 91-113.

28 John Hope to Matthew Boulton, 2 July 1779; 5 August, 1779; 6 August, 1779. Archives of Soho, Birmingham Public Library, reference #MS314/3/376/19-21. Published in Jan Verbruggen, *Correspondence*, pp. 115-117.

29 James Watt to John Hope, 15 August 1779, Archive of Soho, Birmingham Public Library, reference #MS3147/3/81/426. Published in ibid., pp. 118-119.

Hope turned for advice to his engineering consultant, Rinze Lieuwe Brouwer, an Amsterdam merchant and amateur engineer who studied with Allamand at Leiden University and had recently been made a member of the *Bataafsch Genootschap*. Brouwer distrusted Boulton and Watt, as well as the claimed superiority of their design. The descriptions they provided of their engines didn't match the drawings he had seen. Further, Boulton and Watt were clearly fishing for advantage by intimating that Hope should help arrange a Dutch patent for them. Finally, given the job at hand, a Newcomen-style engine would be more reliable and therefore more efficient than a Watt engine; Watt had so much as admitted this in his letter to Hope. It was consequently decided that Brouwer should oversee the project himself.[30]

The few biographical traces Brouwer left behind show him to have been a capable and self-assured, if a physically weakened or hypochondriacal, man. In addition to successfully designing and overseeing the construction of a Newcomen-style steam engine after having seen only one full-scale exemplar (the ill-fated Oostpoort engine), he took it upon himself to investigate the currents and siltage problems in the IJ around Amsterdam. This was a complicated business that demanded the imaginative and skilful dexterity needed to take measurements, the physical and mathematical ability to recognise what needed to be done with these raw measurements and the persevering intelligence to argue against calculations made by competitors.

Brouwer not only benefited from Hope's patronage. He also enjoyed the confidence of Petrus Camper, the Groningen professor famous for his work in comparative anatomy but also quite interested in contemporary engineering issues, and Jan Daniel Huichelbos van Liender, director of the *Bataafsch Genootschap*. Camper and Huichelbos van Liender both depended on him for information ranging from Amsterdam gossip regarding technical matters to technical drawings of apparatus such as the steam-driven pumping system William Blakey was building to cleanse Amsterdam's canals.[31] In Brouwer, we find (as with the instrument-maker Paauw, discussed in the previous section) university education, practical experience and entrepreneurial initiative combined to skilful advantage. He not only had the technical ability and insight to construct a novel contraption. Brouwer knew how to speak to people from various social

[30] On Brouwer as advisor and his recognized intelligence, see Huichelbos van Liender to Jean de Luc, dated 19 December 1783, Archive of Soho reference #MS 3147/3/505/4; copy available at Historical Museum, Rotterdam. For Brouwer's distrust of Boulton and Watt, see Brouwer to Huichelbos van Liender, 15 November 1779, Rotterdam Municipal Archive, Archief Bataafsch Genootschap, inventaris #95, 'Brieven betreffende de vuurmachine aan Huichelbos van Liender 1770-1780'.

[31] See the series of letters from Brouwer to Huichelbos van Liender in 'Brieven'.

levels (the wealthy and workers alike) in order to gain patronage and get work done. And, he was able to defend both the physical and technical principles behind his work in print.[32]

In 1781 Brouwer presented Hope with the first working steam engine ever designed and built exclusively in the Netherlands. Three years later Hope died and Brouwer receded into obscurity. Their machine, however, remained in the garden until 1842. And while Groenendaal was a private estate, both its garden and resident engine became public thanks to the combined forces of tourism and literature. Hope and Brouwer had collaborated to construct an engine capable of managing water, maintaining the aesthetic experience of a landscape park and advertising the worth of novel technology. Other productive skills and the consumption of their embodied effects subsequently conspired to give the Groenendaal engine a rather different purpose and meaning. By the early nineteenth century, it was projected as a naturalised element of Holland's Arcadian landscape, holding out hope that the war-weary Dutch might find a way to regain their moral and material wellbeing.[33]

Groenendaal was situated in a lushly reforested area south of Haarlem, a favoured location for both wealthy estates and numerous inns and restaurants that welcomed tourists taking a short vacation. Anyone planning such a trip could prepare by purchasing a visitor's guide that recommended the best accommodations and tables along with not-to-be-missed sites. Groenendaal appeared prominently within these pages, its seemingly natural beauty actually attributed to the water management skills of its steam engine. Readers were advised to visit on particular days when the engine was in operation so as to appreciate just how it contributed to the Arcadian scenery it helped to create.[34]

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[32] See, for example, Rinze Lieuwe Brouwer, *Wederlegging der aanmerkingen van den heer P. Steenstra over de vuur-machines* (Amsterdam, 1774). Pybo Steenstra, lecturer in mathematics, navigation and astronomy at the Atheneum Illustre in Amsterdam (precursor of the University of Amsterdam), claimed in his own pamphlet of 1772 that steam engines were not an improvement over windmills. See his 'Verklaring der oorzaken van de beurtwisselende beweekinge in de Vuur-Machines; en aanmerkingen, op de groote voordelen, die 'er ons land door genieten zoude, als ze in plaats van watermolens gebruikte wierden,' *Hedendaagsche vaderlandsche letteroefeningen* (1772): 621-638. Steenstra was also involved, much to Brouwer's dismay, in the municipally sponsored project to measure the IJ's current and suggest ways to keep Amsterdam's harbour navigable.

[33] For the naturalization of steam engine technology in the Netherlands, see Lissa Roberts, 'Arcadian apparatus,' pp. 266-269.

[34] See, for example, *Hollandschen weeklijkschennieuws-vertelder* 49 (8 December 1781): 194-194 and L. van Ollefen, *De Nederlandsche Stad- en Dorp Beschrijver* (Amsterdam, 1796), pp. 11-12. Groenendaal and its steam engine continued to be mentioned in tourist literature up through the nineteenth century. See, for example, Jacobus Craandijk, *Wandelingen door Nederland met pen en potlood* vol. 3 (Amsterdam, 1878), p. 362.

Though the harsh realities of revolution and war took their toll on the Netherlands at the turn of the century, making leisure travel less attractive and local considerations less amenable to touristic revelry, they did not diminish the Arcadian longings that stood behind the interests of some of the Netherlands' more eloquent travellers. Since early in the seventeenth century, as Fleischer's essay in this volume attests, Dutch authors had linked their nation's landscape to the literary traditions of Arcadia, domesticating the myth in order to stress how inextricably natural and human history were intertwined in the Netherlands. The Dutch had survived and prospered for centuries by virtue of engineering their national landscape – a landscape in which dense urbanism was balanced by pastoral countryside and material productivity was balanced by a culture of moral responsibility. Thrown out of kilter in the eighteenth century by decades of sensed decline that culminated in the disappointing dislocations of revolution, Dutch culture remained true to its self-image as its literary and painterly spokesmen found refuge in soothing portrayals of their national garden. This was especially true for the Patriot author Adriaan Loosjes, who had actively involved himself in the revolutionary Batavian cause during the 1790s, only to see it set the stage for French dominion.[35]

While Loosjes followed a standing genre of Dutch literature when he penned works such as *Hollands Arkadia of Wandelingen in de omstreken van Haarlem* (*Dutch Arcadia or Strolls in the area of Haarlem*) in 1804, he is of special interest here because of how he embroidered on one of its elements. As indicated above, Dutch portrayals of Arcadia wove the Netherlands' highly urban character into their projections, naturalising industry as part of the Dutch landscape. Jacob van Ruysdael's famous painting *View from the dunes with Haarlem in the distance* (1670-1675) is a vivid and early example of this trend. But at the very time when contemporary English depictions began casting their industrialising countryside in sublime terms, Loosjes continued to emphasise the quiet continuity of technological innovation with the landscape in which it was embedded. Where English patriots turned to the theatre of national heroism and painted scenes of the energetically sublime, Dutch artists and authors remained anchored in the contemplative peace of their Arcadia. Whether describing a new system of sluices erected in 1805 or the Groenendaal steam engine, Loosjes never strayed far from this context, relying on the integrated character of his landscapes to spur a productive reintegration of Dutch society, economy and culture.[36]

[35] On the history of Arcadia as a trope in Dutch literature and painting, see Frans Grijzenhout, 'Wandelingen door Hollands Arkadia,' *De achttiende eeuw* 36 (2004): 132-142.

[36] Adriaan Loosjes, *Hollands Arkadia of Wandelingen in de omstreken van Haarlem* (Haarlem, 1804); idem., *Katwijks zomertochtje* (Haarlem, 1805), p. 71 and passim. For an interesting analysis of English

Conclusion

It is fast becoming a cliché to point out that scientific knowledge, with all its universalist pretensions, is made in specific places. Summing up the wisdom of this trend, the historical geographer David Livingstone notes that locally made knowledge takes on the characteristics of universality because, after its initial production, it travels to places where the local economies of skill and trust enable the creative reproduction or adaptation of what was originally achieved elsewhere.[37] As obvious and salutary as this point is coming to appear, however, its formulation brings with it a number of closely related problems. To begin, it reifies a split between local production and 'subsequent' circulation whereas, in fact, the production of knowledge is most often a function of the circulation process.[38]

Second and perhaps more germane to this essay and the present volume of which it is a part, Livingstone's equation of science with knowledge (consider his title) drives a wedge between science and the network of skills on which he recognises its development to depend. (I leave aside here the ahistoricity of his term 'science'.) But, if we recognise knowledge as a function of practice rather than a synonym for science itself, we are much closer to appreciating the centrality of skill to the processes of both material and knowledge production.[39] This point then sets the stage for resolving two further divisions that underlie Livingstone's analysis: those between science and technology and between production and consumption. In both cases, thinking in terms of 'geographies of skill' rather than 'geographies of scientific knowledge' opens a field within which the criss-crossing trajectories of manual, mental, sentient and social skills – their embodied exertions, effects and consumption – can be mapped out and read as the mundane history by which artefacts and knowledge alike are given form, meaning, momentum and purpose. These lines cut across claimed divisions between science and technology, just as they transgress claimed distinctions between production and consumption, official and popular, pure

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portrayals of industry, especially around Coalbrookdale, see Stephen Daniels, '*Loutherbourg's chemical theatre*: Coalbrookdale by Night,' John Barrell, ed., *Painting and the politics of culture: New essays on British art, 1700-1850* (Oxford: Oxford University Press, 1992).

37 David Livingstone, *Putting science in its place. Geographies of scientific knowledge* (Chicago: University of Chicago Press, 2003), especially chapter four.

38 See, for example, Kapil Raj, 'Circulation and the emergence of modern mapping: Great Britain and early colonial India, 1764-1820,' Claude Markovits, Jacques Pouchepadass & Sanjay Subrahmanyam, eds., *Society and circulation: Mobile people and itinerant cultures in South Asia 1750-1950* (New Delhi: Permanent Black, 2002): 23-54.

39 Lissa Roberts, 'Policy and practice: defining the 'science' in 'science policy',' *Minerva* (under review).

and applied. A review of the small history presented in this essay illustrates how this is so.

To begin, the map represented by this essay is a multi-dimensional one that traces out passage through time as well as space. It is a map that demonstrates skill to be present as a motivating force throughout the entire cycle that we generally speak of in bifurcated terms of production and consumption. As such, it marks the active presence of manually and mentally dextrous inventors and analysts, clever applicants for patents and patronage, entrepreneurs, land-owning aesthetes and landscape architects, eloquent lecturers and equally eloquent writers, adept listeners and readers, travellers and tourists. And, as a geography of skill embodied in the construction, display, use, representation and interpretation of a single set of artefacts, it charts the multi-faceted career of steam apparatus – their various material, intellectual and symbolic manifestations – as they travelled through the Netherlands during the long eighteenth century.

The various sites and guises in which these steam apparatus were constructed and experienced introduce us to an historical landscape very different from what we usually find in histories of steam. On one hand, the question of whether steam engines were constructed through the application of scientific knowledge is out of place here. On the other hand, so is the question of the steam engine's relationship to industrial output or 'retardation'. Instead, we observe how harnessing steam simultaneously led to demonstrations of universal natural laws *and* particular material application; in the case of 's Gravesande, through the agency of one and the same person. We meet it as a vehicle for managing water and aestheticising the landscape; as an instrument of education, knowledge of which was both a source of spiritual inspiration and cultural capital. We encounter the harnessing of steam as a rallying point for civic boosterism and moral regeneration, as a product of social altruism and a means of personal enrichment. Along the way we find that it is only by uncoupling the history of steam from the search for a 'Newtonian culture' and 'industrial vision' that its full richness comes into view.[40]

40 Joel Mokyr, *Industrialization in the Low Countries, 1795-1850* (New Haven: Yale University Press, 1976) and Richard Griffith, *Industrial retardation in the Netherlands, 1830-1850* (Den Haag: Martinus Nijhoff, 1979) both describe Dutch economic history since the end of the eighteenth century in terms of industrial retardation, measuring it in terms of the relatively sparse application of steam power to industrial production. Margaret Jacob begins earlier in the eighteenth century, describing the Netherlands as a place in which what she calls 'Newtonian culture' and an 'industrial vision' didn't take sufficient root to stimulate the kind of progress represented by steam-powered industrialization. See Margaret Jacob, *Scientific culture*, pp. 148-154 and B. J. T. Dobbs and Margaret Jacobs, *Newton and the culture of Newtonianism* (Atlantic Highlands, N.J.: Humanities Press, 1995).

Primary sources

Archief van curatoren van de Leidse Universiteit, vol. 1 (1574-1815), Leiden University.

Archives of Soho, Birmingham Public Library.

Bicker, Lambertus, 'Historie der vuurmachines,' *Nieuwe verhandelingen van het Bataafsch Genootschap* I (1800): 1-132.

Briemen, Jacob van, 'Machine tot het opvoeren van water door vuur,' Nederlands Nationaal Archief, Archive collection Staten van Holland (archive #3515), inventaris #1668, September 1716.

'Brieven betreffende de vuurmachine aan Huichelbos van Liender 1770-1780,' Rotterdam Municipal Archive, Archief Bataafsch Genootschap, inventaris #95.

Brouwer, Rinze Lieuwe, *Wederlegging der aanmerkingen van den heer P. Steenstra over de vuur-machines* (Amsterdam, 1774).

Clerc, Jean Le, 'Éloge de feu de Mr. De Volder Professeur en Philosophie et aux Mathematiques, dan l'Academie de Leide,' *Bibliothèque choisi* 18 (1709): 346-401.

Craandijk, Jacobus, *Wandelingen door Nederland met pen en potlood* vol. 3 (Amsterdam, 1878).

Desaguliers, John Theophile, *A course on experimental philosophy*, 3rd edition (London, 1743).

Gravesande, Willem s', *Physices elementa mathematica experimentis confirmata. Sive introductio ad philosophiam newtonianam* (Leiden, 1720-1721).

Hollandschen weeklijkschennieuws-vertelder

Loosjes, Adriaan, *Hollands Arkadia of Wandelingen in de omstreken van Haarlem* (Haarlem, 1804).

Loosjes, Adriaan, *Katwijks zomertochtje* (Haarlem, 1805).

Luchtmans, Johannes, *Reis naar Engeland in 1772*, Paul Hoftijzer and Jos van Waterschoot, eds. (Leiden: Burgersdijk and Niermans Publishers, 1995)

Ollefen, L. van, *De Nederlandsche Stad- en Dorp Beschrijver* (Amsterdam, 1796).

Priestley, Joseph, *The history and present state of electricity, with original experiments*, 3rd edition, 2 vols. (London, 1775).

Recherches physico-chimiques (Amsterdam, 1792-1794).

Smeaton, John, *Journey to the Low Countries, 1755* (London: Courier Press, 1938).

Steenstra, Pybo, 'Verklaring der oorzaken van de beurtwisselende beweekinge in de Vuur-Machines; en aanmerkingen, op de groote voordelen, die 'er ons land door genieten zoude, als ze in plaats van watermolens gebruikte wierden,' *Hedendaagsche vaderlandsche letteroefeningen* (1772): 621-638.

Detail of Jean Rocque's 'Plan of the Cities of London, Westminster and Southwark', published in 1746.

Wind-gun, air-gun or pop-gun: the fortunes of a philosophical instrument

Jim Bennett

… there is a possibility that you might give a sense and a meaning to this obscure and unintelligible evidence which we have had already, that may connect and apply it to the particular charge, but at present I should say, we have heard a great deal about a turner's shop, and a brass founder's shop, and it is all nothing.[1]

Historians of science generally believe that they deal with episodes of historical consequence played out by actors of some importance. That importance may seem not be fully appreciated by everyone, but the mission of research and the purpose of publication are, in part, to convince readers that assessments need to be revised. Such is not the case for this essay. We begin with a contemporary opinion, quoted above, that the episode in question amounted to nothing at all. Immediately this opinion was formed, on 12 May 1796, it was professed in public by someone skilled in making assessments and confident in passing judgements, namely the Lord Chief Justice of England, and the history of science cannot mount a promising appeal. Despite the profound effect the episode had on individual lives, for the advance of learning it was an exchange of no consequence between characters of scarcely any standing, lasting for only an hour or two. Yet it was focused intensely on inquiry and invention, so comes within the concerns of this volume, and its everyday and inconsequential character make it an unusual subject for detailed study. The commonplace may provide the essential background to innovation and development, but it generally goes unrecorded, unless it happens to intersect with some exceptional train of events: in this case it was lifted from documentary oblivion through allegations of a plot to assassinate the king.

From wind-gun to air-gun

The weapon chosen by the 'infernal regicides', as the main characters of this essay were described at the time, was presented as an invention of fearful

[1] *The Trial of Robert Thomas Crossfield for high treason… Taken in short-hand, by Joseph Gurney* (London: Martha Gurney, 1796) (hereafter cited as *Trial*), p. 79. See also the trial record on line at www.oldbaileyonline.org.

cunning. As a form of air-gun, however, it was a familiar instrument in experimental philosophy. It makes an early appearance, for example, in the organised pursuit of natural knowledge in London. The collection of objects that John Wilkins presented to the Royal Society in November 1663 – generally regarded as the beginning of the Society's 'Repository', before they had purchased the ready-made collection of Robert Hubert – contained, first in the list of sixteen items, 'a wind-gun'.[2] Two items were immediately set to work: the operator was ordered to polish and varnish a burning-glass and to 'fit' the wind-gun.

On 25 November, when the experiments were being determined for the following meeting, the wind-gun was listed alongside the compressing-engine,[3] and on 16 December Robert Hooke proposed an experiment with the compressing engine, 'of applying a gun to it, to see, with what force it will be able to shoot a bullet, arrow, &c'.[4] The outcome was that the engine could compress the air by one half and the shot would then make 'a very considerable dent in a door, sufficient to have killed a man' at a distance of 20 yards.[5]

The development of the wind-gun was considered by the Society from time to time and distinctions between Hooke's or Denis Papin's improvements and the 'ordinary' gun indicate that a wind-gun was not considered unknown or exotic.[6] Papin's version relied on a compression factor of about 60 and the shot could penetrate inch-thick board.[7] He had a version made in the form of a walking-stick.[8]

Even before Wilkins had begun the Society's practical interest in the improvement of the wind-gun, it was a site of natural-philosophical dispute. It was, after all, a very dramatic instance of the old problem of finding the true causal account of projectile motion, made all the more relevant because the causal agent was some action of air. If the motion of the air was the cause, as it would be in the Aristotelian natural philosophy, the instrument was properly called a 'wind-gun'. If, however, some property of the air, such as a mechanical springiness under compression, explained the gun's action, air in a particular

[2] Thomas Birch, ed., *The history of the Royal Society of London* (London: A. Miller, 1756-7), pp. i, 324; Nehemiah Grew, *Musaeum Regalis Societatis* (London: W. Rawlins, 1681), p. 366; Oliver Impey, and Arthur MacGregor, eds., *The origins of museums: the cabinet of curiosities in sixteenth- and seventeenth-century Europe* (London: House of Stratus, 2001), pp. 220-1. This generosity prompted the Society to draw up a list of benefactors, which, alongside Wilkins, included Prince Rupert for his water-engine (a pump for raising water), Seth Ward for his pendulum clock and Robert Boyle for his pneumatic-engine (the air-pump).

[3] Thomas Birch, *History,* i, p. 335.

[4] Ibid., p. 345.

[5] Ibid., pp. 367, 396.

[6] Ibid., ii, p. 436.

[7] Ibid., iii, pp. 401, 503-4, 508, 510; iv, 456, 459, 460, 494-5.

[8] Ibid., iii, p. 518.

condition could be seen as the 'charge' for the gun, which would more properly be called an 'air-gun'. Changes in nomenclature are important, even if they take place slowly: 'wind-gun' remained the most common name through the seventeenth century, though 'air-gun' was used occasionally in the 1680s at the Royal Society.[9] By the early eighteenth century 'air-gun' was becoming more common, though 'wind-gun' was occasionally used throughout the period under study.

For the early Royal Society this mechanical treatment of the air could be elaborated in two complementary ways. The phenomena of the dramatic compression and forceful but spontaneous expansion of the air could readily be conceptualised in mechanical terms – in terms of the 'spring' of the air, by analogy with mechanical springiness. At the same time practical applications could be developed, since the air could be made to perform mechanical work, such as shooting guns.

Boyle referred to the wind-gun in some of his earliest accounts of the spring of the air, and he continued to cite 'Wind-Guns, and other pneumatical Engines' when evidence of the extreme compressibility and springiness of the air suited his purpose.[10] But the wind-gun did not favour any particular natural philosophy. Whatever account was given of the spontaneous expansion of air, the wind-gun was an impressive instance that could be cited in its support. Henry More, Marin Mersenne and Thomas Hobbes each gives his account,[11] and as early as 1644 Kenelm Digby had used the wind-gun to refute Galileo's claim that the air could not sustain the violent motion of a heavy body. Here was dramatic proof of Digby's Aristotelian account of projectile motion maintained only by the force of the air:

> … the experience of windgunnes assureth vs that ayre duly applied is able to giue greater motion vnto heauy bodies then vnto light ones. For how can a straw or feather be imagined possibly to fly with halfe the violence as a bullet of lead doth out of one of those engines?[12]

In a gesture that echoed Wilkins in 1663, William Petty offered a much more extensive collection of philosophical equipment to the Dublin Philosophical Society in the mid-1680s, among which was 'a condensing pipe or wind-gun',[13]

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9 Ibid., pp. iv, 376-7, 459.

10 R. Boyle, *New experiments and observations touching cold*, (London: John Crook, 1665), p. 314; *New experiments physico-mechanicall, touching the spring of the air* (Oxford: H. Hall, 1660), pp. 32, 252-3; *New experiments physico-mechanical, touching air* (London: Richard Davis, 1682), pp. 15, 17, 27, 53, 128.

11 H. More, *The immortality of the soul* (London: William Morden, 1659), p. 336; *Remarks upon two late ingenious discourses* (London: Walter Kettiby, 1676), p. 174; S. Shapin and S. Schaffer, *Leviathan and the air pump* (Princeton: Princeton University Press, 1985), pp. 84, 231, 368.

12 K. Digby, *Two treatises in the one of which the nature of bodies, in the other, the nature of mans soule is looked into in way of discovery of the immortality of reasonable soules* (Paris: Gilles Blaizot, 1644), pp. 104-5.

and as cabinets of physics were created in the eighteenth century, the air-gun took its place within this instrumental and experimental culture.

The air-gun is included in surviving collections,[14] it is listed in the syllabuses for lecture courses[15] and it is dealt with in popular textbooks, such as those of George Adams and Benjamin Martin.[16] It was considered appropriate material for inclusion in Martin's, *The young gentleman and lady's philosophy* (editions of 1772 and 1782), introduced in the context of the condensing engine. The sister Euphrosyne pronounces this 'a Philosophical Method of shooting, truly!'[17] The gun illustrated is self-contained, with the air being compressed by a piston in the stock, but a footnote mentions that 'Of late there is a much better Form of an Air-Gun invented,' where copper bottles containing the compressed air were charged by the condensing engine and fitted to the gun as required. Adams agreed that 'the present mode of making them' involved carrying the condensed air in metal balls. When William Jones came to edit a new edition of the Adams text in 1799 he added an illustration of this 'air-gun of the most modern and approved construction'.[18] It is clear that the air-gun was perfectly well known, both to gun-smiths (as we shall see) and to practitioners of experimental philosophy in the late eighteenth century.

From air-gun to pop-gun

Despite this familiarity and apparent innocence, a mysterious form of air-gun took on the character of a diabolical invention at the centre of a trial for treason conducted at the Old Bailey (the criminal courthouse next to Newgate Prison in London) in May 1796.[19] It was a time of unrest, anxiety, radical debate and government repression. Encouraged and inspired by the French example, small sections of the British public were willing to challenge for reform, if not revolution. An exaggerated fear of upheaval provoked official action against popular radical societies, one of the most famous being the London Corresponding Society, to which many of the figures in this story belonged.

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13 Thomas Birch, *History*, pp. iv, 397-8.

14 E. Lefebvre and J.G. de Bruijn, eds, *Martinus van Marum. Life and works*, vol iv, G.L'E. Turner and T.H. Levere, *Van Marum's scientific instruments in Teyler's Museum* (Leiden: Noordhoff, 1973), p. 233; A.Q. Morton and J.A. Wess, *Public and private science: the King George III Collection* (Oxford: Oxford University Press, 1993), pp. 258-9, 286-8.

15 James Ferguson, *Syllabus of a course of lectures …* (Edinburgh, 1768), p. 10.

16 G. Adams, *Lectures on natural and experimental philosophy* (London: R. Hindmarsh, 1794), i, pp. 86.

17 Benjamin Martin, *The young gentleman and lady's philosophy* (London: W. Owen, 1772), i, pp. 406-7.

18 G. Adams, *Lectures on natural and experimental philosophy* (London: W. & S. Jones, 1799), i, pp. 133-4.

19 John Barrell, *Imagining the king's death: figurative treason, fantasies of regicide, 1793-1796* (Oxford: Oxford University Press, 2000), especially chapter 14; see also Alan Wharam, *Treason: famous English treason trials* (Stroud: Alan Sutton, 1995), pp. 100-14.

Habeas Corpus was suspended in May 1793 and the year 1794 in particular saw a number of trials of radicals and reformers,[20] including those of Thomas Hardy, the Scottish shoemaker who had founded the Society in 1792, John Horne Tooke, prominent in the Society for Constitutional Information and John Thelwall in the London Corresponding Society.

The London Corresponding Society, with many tradesmen and artisans among its members, had a less elevated social profile than the older Society for Constitutional Information. The characters who first enter the story of the treason plot, all members, are typical. Thomas Upton was a watchmaker with aspirations to be a mechanic of a broader and more inventive scope. He lived and worked in Bell Yard, off Fleet Street. Peter Thomas Lemaitre was a maker of watch cases; he lived and worked in Denmark Street, Soho, and was only 18 years old when the episode began. George Higgins – 'druggist' as cited in the indictment – worked 'behind the counter' as warehouseman or shopman to Messrs Barclay and Co., Druggists, in Fleet Market. Higgins described his workplace as 'a medicinal warehouse', and his master was referred to at the time as a 'chymist and apothecary'.[21] John Smith was a clerk in a print gallery who also published pamphlets and ran a radical bookshop at his home in Portsmouth Street, Lincoln's Inn Fields. These men's names became linked through an alleged, indeed a fabricated, conspiracy, which led to their arrest for 'compassing and imagining the death of the King'.[22] The fabrication of the plot originated in the coincidence of two sets of interests in its invention – the interests of Thomas Upton and those of the government.

Upton was an able and intelligent man, but he had an unstable and mercurial temper as well as a dubious past, containing allegations of fraud and other crime, which was becoming known to fellow members of the London Corresponding Society. Concerns about spies and government informers meant that there was unease and suspicion within the Society, as well as anxiety that its reputation would be compromised and its cause undermined. Upton's standing had been such that he had been one of nine members authorised to receive contributions to a subscription organised for the wives and children of the imprisoned members, but he was now removed from the list and was asked to consider leaving the Society. At a meeting of the General Committee in September 1794, where Higgins and Lemaitre proposed a vote of censure on Upton, Lemaitre remarking that he 'does not deserve the name of '*Citizen*',' Upton's fury was spectacular. At one point he seemed to be preparing to leave before the vote could be taken, whereupon Higgins warned the committee

[20] Alan Wharam, *The treason trials, 1794* (Leicester: Leicester University Press, 1992).

[21] J. Smith and G. Higgins, *Assassination of the King! The conspirators exposed* (London: J. Smith, 1795), p. 70.

[22] The commonly used formula, for example, *Trial*, p. 17.

that the motion should be put immediately, since Upton appeared to be 'hopping off', so as to avoid a reprimand. Upton was lame and took this remark as a personal insult.[23] Although he received the apology he demanded, it was a remark he would cite thereafter as 'a reflection upon my natural infirmity'. He threatened dire retribution on Lemaitre and Higgins, and when the vote of censure was passed, his rage was such that 'it was impossible for Twenty Men to keep him in any sort of Order'.[24]

Upton's disclosure to the authorities of a plot to assassinate the king came shortly afterwards. He represented himself as a conspirator alongside Lemaitre, Higgins and Smith, but claimed that he had adopted the role of a spy, and had acquiesced only so as to discover the truth and report the plot. He was to have made the air-gun and had been drawn into the plan because he was 'an Artist and a Mechanic and might be of use on that account'.[25] His evidence was a drawing of the gun and of a poisoned dart it was to fire, which he said was in the hand of Lemaitre, two pieces of wood that he said were patterns for the gun, and an incriminating letter from Lemaitre. He later produced a further letter from Lemaitre to Higgins and a two-foot long brass tube he said he had been given by Smith. The dart had a mechanical action, such that hitting the target activated two forks that attached it to the victim while the poison was injected from a glass tube. Higgins was to have supplied the poison.

Far from being a regular item of commerce and demonstration, this air-gun was represented in the press as the outcome of great mechanical cunning, an invention made possible only by the application of a ruthless ingenuity, whose origins in the arcane culture of mechanical invention only added to the instrument's mystique and the reader's apprehension.[26] Every opportunity was taken in the official discourse to reinforce such fearfulness, with references, for example, to 'the instrument', rather than simply to a gun. *The Times* reported that when Mr Mortimer, 'the ingenious gunsmith', was called upon to examine the drawings produced by Upton, he pronounced the mechanical poison dart 'one of the most artful pieces of workmanship he had ever seen,' though he added that it was not quite perfect and that the design had been taken from a description in 'the Encyclopœdia'. He judged the means of delivering the dart 'constructed in the perfection of fiend-like malice'.[27] Even the theatre column

[23] National Archives, TS 11/547. Paul Thomas Lemaitre, *High treason!! Narrative of the arrest, examinations before the Privy Council, and imprisonment of P.T. Lemaitre* (London: J. Smith, 1795), pp. 53-4. See also the accounts of Hill and Bone, *Trial*, pp. 72, 198.

[24] John Barrell, *Imagining*, p. 456. Note also Palmer's and Hill's evidence in *Trial*, pp. 62, 71-2.

[25] John Barrell, *Imagining*, p. 460.

[26] The *True Briton*, for example, announced 'an air machine, of a particular construction'. The *Oracle* described its maker, Upton, as 'an artist highly ingenious'. For press comment, see John Barrell, *Imagining* , pp. 446-52. Note also *Trial,* p. 284.

in *The Times* contributed by identifying the inspiration of 'the infernal Regicides' not in the *Encyclopédie* but in Hamlet:

I bought an unction from a Mountebank
So mortal, that but dip a knife in it,
When it draws blood, no cataplasm so rare,
Collected from all the simples that have virtue
Under the moon, can save the thing from death.[28]

The record of the examination before the Privy Council of the three accused is preserved at the National Archives in Kew.[29] They each denied the plot, and even that they had more than a passing acquaintance with each other. Lemaitre said that the drawing and letters were forgeries and that he had never before seen the wooden patterns. The examination increasingly revealed the flaws in Upton's story, but instead of the Council concluding that Upton was inventing it, such was their inclination to find treasonable plots – not least to reinforce a general public alarm that would help justify other action against reform – that their conclusion was instead that Upton was not being candid about what he knew and increasingly he found himself under suspicion. Accordingly he elaborated his story, at one point describing the original conversation with Lemaitre, Higgins and Smith, when he was recruited to the plot, and had Higgins, for example, saying: 'Aye by God we will dish Georgy, Pitt and Dundas'[30] – respectively the king, the prime minister and the home secretary.

As the interrogation continued and as genuine spies received reports that seemed of possible relevance, a further mechanic and member of the London Corresponding Society entered the drama. John Hill was a turner who became concerned that he had executed an order from a customer to make a model for casting a brass tube. Talking about his concerns led to his being arrested and examined. Upton had to adjust to this development because, although his attempts to implicate and revenge himself on Lemaitre, Higgins and Smith had led him to invent a story involving them, this story seems to have been suggested to him by a real attempt he had himself made to build a form of air-gun, an attempt that had nothing to do with the three accused. Hill had been one of the artisans Upton had turned to for assistance, and if Hill were now to tell his story, where Upton would figure in the making of the weapon, but none of the others, Upton's situation would become even more precarious. Upton now decided to tell a story that, although far from being the truth, was extended

[27] *The Times*, 2 October 1794, p. 2; for Mortimer's evidence, see National Archives, TS 11/547.
[28] *The Times*, 4 October 1794, p. 3.
[29] The relevant records are at the National Archives, Kew, TS 11/547; PC 1/31/77.
[30] National Archives, TS 11/547.

to include events that had actually happened, and that would cover what Hill was likely to say. In doing so he introduced two new characters. One was an attorney, Peregrine Palmer, the other a physician, Robert Thomas Crosfeild.[31] Both were members of the London Corresponding Society, but neither seems to have been connected with the original quarrel, nor did Upton have any particular reason for animosity towards them; they were simply needed to meet the increasing challenge of maintaining his credibility.[32]

Crosfeild had taken his medical degree in Leiden.[33] A tall man of an outgoing, light-hearted and engaging character, he enjoyed company, conversation, drinking, singing and playing music. At the same time, he was a humane and committed physician, a talented linguist – both ancient and modern – and a radical reformist. The latest version of Upton's story focused on a particular day when, at his home in Bell Yard, Crosfeild and Palmer, along with Smith and Higgins, were trying to persuade him to make 'an Instrument', which Upton took to be a 'new invention'. A turner would be needed and Higgins proposed John Hill, who like all the rest was a member of the Society, and who could make patterns from a sketch supplied by Crosfeild. Hill had made the wooden vertical supports for Upton's leg irons, Upton knew where he lived and offered to show the others, but Smith and Higgins had conveniently left the company by the time its three remaining members arrived at Hill's shop in Bartholomew Close. When Hill was examined on this account, he agreed that Upton, Palmer and a man he did not know had visited his shop, and that he had made patterns according to a sketch they provided. These, it turned out, had been the patterns Upton had previously produced.

The Privy Council were losing faith in Upton through all the elaborations of his story and he was arrested and charged with high treason, as were Lemaitre, Higgins and Smith. With the four accused in separate prisons, the Council wanted to proceed to examine Palmer and Crosfeild, but seemed to be in no hurry to do so. Eventually Palmer was questioned in December, he agreed that he, Crosfeild and Upton had indeed visited Hill's shop, but none of the other accused had been involved. Nonetheless, as the questioning continued and the case against them seemed to fall apart, they were still kept in custody until May 1795 and were then released on bail. This action seemed to confirm to

[31] Sometimes, for example in the record of the treason trial, spelt 'Crossfield'. We have used the spelling Crosfeild adopted in his publications.

[32] Indeed counsel for Crosfeild at the eventual trial believed that Upton had tried to persuade Hill to swear before the Privy Council that Lemaitre, and not Crosfeild, had been present when Hill received a commission from Upton to make the model, *Trial*, pp. 74-5.

[33] Crosfeild was born in 1759, matriculated at Leiden in 1788, took his MD in 1791, died in 1802, R.W. Innes Smith, *English-speaking students of medicine at the University of Leyden* (Edinburgh: Oliver and Boyde, 1932), p. 58.

sympathisers the government's bad faith in the whole matter of the alleged plot. If it was really thought that the accused had been plotting the assassination of the king, they could hardly have been allowed bail. If, on the other hand, they were thought to be innocent, the charge of treason should have been dropped.

When in February a reward was announced for the apprehension of Crosfeild, he had already left the country. In fact we know where he was at around this time with surprising precision, even though he was not on hand to be apprehended, for in Newgate Prison Smith received a letter from Crosfeild addressed 'At Sea, Lat. 43.23. Long. 4.10. west'.[34] Crosfeild had gone to Portsmouth on 20 January and signed up as ship's doctor on a whaler bound for the South Seas. Only a few days out of port, however, it was captured by the French and Crosfeild taken prisoner. After the capture of a further British ship, they sailed to Brest, where the prisoners were kept on prison-ships in the harbour. Eventually Crosfeild and a number of others were exchanged and returned to England, where, after a fellow-prisoner had informed on him, he was arrested on 31 August 1795.

There then began a new round of interrogation. None of the brass-founders could identify Crosfeild, and the turner Hill was unsure whether he had been the third visitor to his shop. Crosfeild would not answer questions and seems to have kept up his generally jocular attitude to things even before the Privy Council. Lemaitre, Higgins and Smith were examined once again. Crosfeild was sent to the Tower, on a charge of high treason, but the others, though still on bail, did not imagine that they were in any further danger, and it was around this time that they published outraged accounts of their treatment during their former arrests, interrogation and imprisonment. Two pamphlets appeared, one written by Lemaitre,[35] the other jointly by Higgins and Smith,[36] and Smith published both 'At the Pop-Gun, Portsmouth Street'. Such was Smith's confidence and contempt that he – comfortable in his notoriety – had hung a new sign, the Pop-Gun, over his shop and changed his address accordingly.

The air-gun was now the pop-gun, the name of a child's toy, intended to provoke ridicule as a weapon no less absurd than the story of the plot in which it starred. Crosfeild was one of the first to use the term in this way, writing of Upton in his letter to the imprisoned Smith, 'I heard no more of him or his pop-gun …'. Among all the other quarrels, this was also a squabble about names. Throughout the trial, the prosecution scarcely ever referred to 'the air-gun', but almost always preferred 'the instrument' – at once more sophisticated, technical, mysterious and sinister. In October, on the other hand, Lemaitre

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[34] J. Smith and G. Higgins, *Assassination*, p. 28.
[35] P.T. Lemaitre, *High treason!!*.
[36] J. Smith and G. Higgins, *Assassination*.

received a letter from 'Citizen' John Bone of the London Corresponding Society, where he referred to 'that infernal ministerial scheme now very properly called the Pop-gun Plot'.[37]

Despite, or perhaps because of their ridicule and contempt, to the surprise of nearly everyone concerned, the indictment of Crosfeild in January 1796 on a charge of high treason, included also Lemaitre, Higgins and Smith. Upton was not included, as he was to give evidence against them. Again this move was seen as a cynical ploy by the government to maintain the sense of alarm and justify repressive legislation and action against Corresponding Societies. The prisoners were to be dealt with separately, Crosfeild first, and after further delay his trial opened on 11 May.

From the start there were further extraordinary twists to the tale. The prosecution announced that their chief witness, Thomas Upton, was dead.[38] They implied that the occasion had been suicide, and a boatman had brought Mrs Upton her husband's hat, as proof of his demise. The boatman, Thomas Annis, was not called but the prosecution brief, preserved at the National Archives, indicates that Annis's story was more colourful than a simple suicide. Although Mrs Upton claimed that she 'never saw him disguised in liquor in my life,'[39] Annis had found Upton in a public house in Deptford very much the worse for drink and had had great difficulty 'pouring him', in his words, into his boat. Shortly after their departure for Wapping, where Upton was now living, he had stood up to relieve himself over the side and had tumbled into the Thames, never to rise again. No body had been found, only his hat. The defence believed none of this and claimed to have witnesses who had seen Upton perfectly alive only the previous day.

Who stood to gain from the alleged impossibility of calling Upton to testify? He should have been the most important witness for the prosecution, but his testimony under examination had proved so changeable that he may instead have been a liability. From the defence point of view, on the other hand, it was very helpful that the more of the story Upton had divulged, the more he seemed to be the chief conspirator – the one who took the lead in designing, procuring and paying for the components of the 'instrument'. There is evidence that Upton was indeed alive, not least that a payment was made to him by the Home Office some two and a half years after his alleged drowning.[40]

[37] P. T. Lemaitre, *High treason!!*, p. 60. Bone was a muslin cleaner; he was a witness for the defence in the trial of Crosfeild, *Trial*, pp. 196-200.

[38] *Trial*, p. 25; R. T. Crosfeild, *Remarks on the scurvy* (London: J. Ridgway, 1797), p. iii.

[39] *Trial*, p. 129.

[40] John Barrell, *Imagining*, p. 499.

There were two main components in the prosecution's case against Crosfeild, referred to as the 'confessional' part of the evidence and the 'instrumentary' part. It is the record contained in the latter part that is relevant to this article, which in a way is unfortunate, as the stories of Crosfeild's behaviour at sea, as related by his fellow travellers, make entertaining reading. The evidence from prosecution and defence witnesses alike allowed counsel for the defence to present Crosfeild as a harmless, good-natured buffoon: he was no saint, but that did not mean that he was guilty of treason, '… whatever the levity of his character may be… and whatever his debaucheries may be with respect to wine, or opium, or women'.[41] It was difficult to take much that Crosfeild was prepared to say – or to sing – particularly seriously: his general levity seemed to be such that he was willing to say the most outrageous things for his amusement, and in any case what he said was often influenced by alcohol. The case for the defence was that the 'confessional' evidence was doubtful, inconsistent and undermined, while the 'instrumentary' evidence, which we shall turn to next, did not show any ill intention on the part of Crosfeild.

In the prisoner's short address to the jury, he claimed that his innocence was not compromised by 'however occasionally I may have appeared imprudent in words or in actions'.[42] The jury agreed and, after a trial lasting two days, found Crosfeild not guilty, despite an adverse summing-up from the Lord Chief Justice. A week later Lemaitre, Higgins and Smith were brought to court and a jury sworn, but the Attorney General announced that, with Upton dead, there was insufficient evidence against them and they were immediately acquitted.

An incident in the history of experimental philosophy

It has been necessary to tell the story of the 'Pop-Gun Plot' for us to understand both the context for an episode in experimental philosophy and why any record of it has survived. As historians of science we are accustomed to more isolated narratives but it can also be useful to witness experimental and instrumental aspects of London life alongside all the other more newsworthy events. It is these events that have opened up this episode to scrutiny and documentation, and in turn allowed us to see activities involving experimental philosophy and mechanical invention as they happen incidentally and contingently within other currents of metropolitan life. But we can now turn more particularly to these activities from two perspectives. One is to consider what

41 *Trial*, p. 185.
42 Ibid., p. 253.

we can learn in general terms about experimental philosophy in this society; the other is to take the unusual opportunity of focusing down on a single day, a single afternoon. It was an afternoon of no apparent importance or consequence at the time, but the scrutiny it received subsequently has recorded it for us in unusual detail.

First the episode gives us an opportunity to see how experimental philosophy and mechanical invention figure in the everyday lives of actors whom we would not normally come across in any history of science. We have encountered these Londoners for other reasons. Crosfeild, though still obscure by normal standards, comes closest to qualifying for the historian's more regular scrutiny through his publications. He qualified in Leiden, and his dissertation was published there in 1791.[43] It is dedicated to Joseph Black, and with reference to respiration it introduces a discussion of the views of Lavoisier and Priestly on phlogiston. Crosfeild also contributed to the periodical literature in medicine. He planned to make experiments on the waters of Bristol and Bath.[44] More particularly for the story of the treason plot, while he was in the Tower awaiting trial, he wrote, 'during my dreary confinement', a treatise on scurvy, based on his experience with his fellow prisoners in the harbour of Brest in 1795. His *Remarks on the Scurvy* was published in 1797, dedicated to the members of the jury who had acquitted him, each one listed by name – names that had, by the rejection of the advice of the judge, been recorded 'in letters of adamant among the glorious assertors of your country's rights'.[45] Here he explained his reasons for setting sail in 1795 in terms that emulated Joseph Banks:

> … it was simply in consequence of a plan I had long before formed of visiting the southern hemisphere for the purpose of cultivating natural history; I had provided every thing necessary for bringing home an extensive collection, together with an astronomical, chemical, and anatomical apparatus.[46]

Crosfeild gives a vivid description the conditions in the prison ships and the medical practice he carried on among the prisoners. He had plenty of opportunity to observe and treat scurvy and his conclusion was that 'the only radical cure… was to be obtained not from medicine but from change of diet'.[47] The only exception was that opium, 'prudently administered', could relieve the

43 R.T. Crosfeild, *Dissertatio medica inauguralis quaedam de arthritide genuina complectens* (Leiden: Frates Murray, 1791).
44 *Trial*, pp. 64, 67
45 R.T. Crosfeild, *Remarks*, p. i.
46 Ibid., pp. iii-iv. Crosfeild told the Privy Council, 'he meant to go to some Country where he could Exercise the Talent he had for cultivating Natural History', National Archives, PC 1/31/77, 14 September 1795 / Treason 'Further Examination relation to Crossfield'.
47 R.T. Crosfeild, *Remarks*, p. 19.

symptoms for many days, until 'some hospitable shore may afford the only radical cure – dry air, moderate exercise, and plentiful diet'.[48] The avoidance of the disease in the first place could be achieved without difficulty and he recommended the regime introduced by 'the illustrious Captain Cook'. Good management was essential for providing appropriate clothing and other supplies, for the sailors could not be trusted to look after such necessities for themselves: 'Few of them have the fortitude to resist the temptations of a glass of gin or a strumpet; and, to indulge themselves in those pleasures, they will, without scruple, expend their last farthing, and go to sea in the most deplorable condition'.[49]

Crosfeild offered more general observations on the *materia medica* and an advertisement reveals that he would soon publish his translation of the works of Hippocrates and an account of the life of the Greek physician. Crosfeild's conclusion showed that, despite all his experiences, his underlying idealism was still alive. For a ship stricken by scurvy there should be no such thing as an enemy port, and this would be possible, since if a man is free to act on his own instincts, 'they are for the most part generous, great, and good'.[50]

Moving to the even more obscure figures in our story, a further intriguing glimpse of everyday natural philosophy comes from the record of Upton's interaction with the mathematical instrument maker David Cuthbert, who had a shop in Graham Court, Arundel Street, off the Strand, not very far from Upton in Bell Yard. This came out in the interrogations and in court, because it related to Upton's interest in pneumatics.[51]

Cuthbert belonged to the London Corresponding Society and called on Upton, so as to make a subscription for the wives and children of those in prison. By the time he called again, to enquire how the subscription was going, Upton's troubles in the Society seem to have begun. This would have been a natural topic of conversation, as the Society were moving to deprive Upton of the right to collect subscriptions, but the prosecuting counsel stopped Cuthbert relating this in court, thinking he was digressing into irrelevancy, or perhaps likely to reveal too much of Upton's animosity towards some of the accused.

Cuthbert invited the watch-maker Upton to see a wheel-cutting engine he had in his shop. He thought this would be 'a treat to him, as being in that line',[52] the more so as the engine was an unusual one. Upton came, but seemed

[48] Ibid., p. 20.
[49] Ibid., p. 21.
[50] Ibid., p. 37.
[51] *Trial*, pp. 44-8.
[52] Ibid., p. 45; National Archives, TS 11/547.

more interested in an air-pump that Cuthbert had in his shop. Cuthbert explained the action of the pump, 'in the best manner I could', and then showed him an air-gun, explaining it also 'in the best manner I could'. Thus Cuthbert followed the classic pattern of such explanation – not unlike the method of Benjamin Martin – first the air-pump for rarefaction, then the air-gun for compression. While the practice of such explanation and demonstration in the London shops of the eighteenth century is well known,[53] it is still surprising to find an air-pump in the shop of a mathematical instrument maker.[54]

Upton was so impressed by all this that he came back the next day to examine the gun again and to show it to a companion. Under cross-examination it emerged that Upton knew little about 'the properties of air' and Cuthbert had taken it on himself to educate him. The clear impression from the record is that Cuthbert saw it as a natural thing to talk about such matters and to pass on what he knew. Having the air-pump in his shop was part of that practice within the shop space. It is perhaps not surprising to find that Benjamin Martin was a particularly extreme and emphatic example of a more widespread tradition in his trade. Cuthbert threatened to be too loquacious on other topics, and had been checked on that account by counsel for the Crown, but now his answers are flat and matter-of-fact, and offer no elaboration or explanation:

Q. You say you invited Upton to come to your house to look at an engine of yours, which you thought might entertain him?
A. Yes.
Q. Having an air-pump in your shop induced you to talk to him about the properties of air?
A. Yes.
Q. Had he asked you any thing about the properties of air before you introduced the subject?
A. I do not think he did.
Q. Did he appear at the time to be conversant with the properties of air?
A. I do not think he was.
Q. And therefore he asked you for the purpose of enlightening his ignorance?
A. Yes[55]

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[53] James A. Bennett, 'Shopping for instruments in Paris and London,' in *Merchants and marvels: commerce, science, and art in early modern Europe*, ed. Pamela H. Smith and Paula Findlen (New York and London: Routledge, 2002), pp. 370-395.

[54] A probate inventory of 1741 lists an air-pump in the shop of an optician and optical instrument maker, Nathaniel Adams; it is the only exception to items of optical trade in his shop, P. Buchanan and B. Gee, 'Inside the shop of an eighteenth century optician,' *Bulletin of the Scientific Instrument Society*, no. 82 (2004): 10-15.

[55] *Trial*, p. 47-8.

Upton had already made his own progress within this experimental discourse of the tradesmen and mechanics. Palmer was asked in court, by the defence counsel, whether Upton was 'a mechanic in any other respect than as a watchmaker'. (This was probably to show that he had the ambition and ability to do more than execute the designs of others.) Palmer's reply was:

> I remember seeing at his shop an electrical machine that he had made, which he shewed us as a curiosity.[56]

So, if it seems surprising to find Cuthbert the mathematical instrument maker with his air-pump and air-gun, it is at least as striking for a watchmaker to have an electrical machine. Note that Upton used it in just the same way as Cuthbert used his air-pump. It was not an item of trade in the normal sense. Although he kept it in his shop, he showed it 'as a curiosity'. Experimental philosophy could be part of the unexceptional and everyday fabric of the lives of forgotten Londoners in the 1790s.

While the government sought to raise a spectre of cunning mechanics and infernal instruments, the air-gun, even when disguised as a walking-stick, was an item of open commerce in Fleet Street. This led to the oddity of a gunsmith readily identifying the sinister drawing shown him by the Privy Council as an air-gun, and pointing out that he made and sold much better ones in his shop. When counsel for the defence, who would have to agree that there had been interest in making some form of air-gun, pointed out that this did not imply any inappropriate intention, the alternative application was in the area of curiosity and experiment. He contended that '… there is no particular colour or complection given to this, that takes it out of the situation of a common instrument, for a mere matter of mechanical curiosity'.[57] He later stated the alternatives for the instrument as 'perhaps meant for the purposes of experiment, perhaps not'.[58] It is ironic that what was perhaps the finest philosophical air-gun in the country was owned by George III himself. Its most prominent component was a brass tube of just over three feet long, which served as a barrel that could be connected to a compressing engine. It is also remarkable that it has survived with the accessory of a brass dart with a steel point. By the time of the 'Pop-Gun Plot' it had been in the royal collection of philosophical instruments for over thirty years.[59]

In the final part of this essay we shift attention from episodes that are relatively transient and obscure to one that is utterly fleeting and insignificant – a

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56 Ibid., p. 61.

57 Ibid., p. 81.

58 Ibid., p. 170.

59 A.Q. Morton and J.A. Wess, *Public and private science: the King George III Collection* (Oxford: Oxford University Press, 1993), pp. 258-9, 286-8.

mere moment in the history of experimental philosophy and mechanical invention that has been opened to our examination by the record of the 'Pop-Gun Plot'. The extent of the documentation is unusual, those involved having been carefully examined both at the Privy Council and later in court, separately by prosecution and defence counsel, and it is particularly unusual to have several views of specific encounters. Elsewhere we have accounts from people seeking to procure instruments but no impressions from *behind* the counter.[60] Every detail of the following account of the afternoon in question (except for the precise details of the route) is documented.[61]

The day is Monday, 8 September 1794, and the record begins with Crosfeild and Palmer dining together. This is around the middle of the day and they dine 'somewhere in the neighbourhood of Temple-bar'. Crosfeild is in poor health; we know from Palmer that he is taking 'large quantities of opium' at the time.[62] Crosfeild lives in lodgings in Dyers Buildings, off Holbourn; he is married but his wife is not living with him at present. Palmer lives close by – scarcely any distance along Holbourn, in Barnards Inn. They are very good friends and have known each other for fifteen or sixteen years. Whenever asked, Palmer will acknowledge a 'great intimacy' between them. If they have come from home, either separately or together, they will have walked down Fetter Lane or Chancery Lane to Fleet Street, with Temple Bar at its western end.

Crosfeild and Palmer have some business to see to in the City, so their natural route after dinner would be east along Fleet Street. However Upton has been repairing a watch for Palmer and, since his premises in Bell Yard are nearby, the two friends call there first to collect Palmer's watch. Upton is doing well in his business at this stage. In Bell Yard he is well placed for custom between the law in Lincolns Inn Fields and the commerce of Fleet Street. The next street to the east is Chancery Lane and scarcely any distance to the west is the Strand. As a consequence of the events that are to unfold, he will lose his business and be obliged to move to Smithfield and eventually to Wapping, but at this stage his business is worth £300 and his weekly income is two guineas.[63]

Upton also has ambitions. He has an idea for an instrument – a form of air-gun – and he takes the opportunity of discussing this with Crosfeild, who is a

60 J.A. Bennett, 'Shopping'.

61 *Trial*, pp. 26-8, 35-44, 48-64, 68-71, 288-95.

62 Ibid., p. 61.

63 These figures come from Upton's later requests to the Privy Council for compensation, on account of the service he did the king. John Barrell, *Imagining*, p. 480.

travelled, educated, professional man with at this time, by his own account, an interest in instruments – the 'astronomical, chemical, and anatomical apparatus' that will assist his planned expedition to the southern hemisphere. Crosfeild is drawn into giving his advice, as he will later explain in his letter to the imprisoned Smith:

> … Upton told me he was making an air-gun … He shewed me two brass tubes, one for the barrel and one for the magazine, which was too weak; on this I gave him what I conceived to be proper dimensions, and in company with Mr. Palmer, went to Hill to bespeak models.

Upton will now need to have a new magazine cast for him in brass and to find the artisans he needs – in particular, as we shall see, to replace his inadequate tube with one made to Crosfeild's specification – he will have to go in roughly the same easterly direction as Crosfeild and Palmer. It is agreed that they will set off together, with Upton no doubt expecting to benefit from the presence and apparent expertise of Crosfeild. Together they should be an effective partnership: Upton understands the world of manufacture and trade, Crosfeild seems to be familiar with philosophical instruments and the spring of the air.

Upton is not an ordinary shopper: he is not like, say, a gentlemanly natural philosopher who would buy a complete instrument and perhaps imagine that it has all been made in the workshop associated with the shop where he makes his purchase.[64] Upton is an insider, who knows about the trade in fine mechanical goods. He is well used to the practices of subcontracting, where parts might be secured from a range of different specialists and perhaps not even assembled by the person whose name is on the finished piece. This was particularly true of watch making. Upton is after parts and wants to source them reliably and reasonably, and he certainly does not want to broadcast to the trade whatever idea he thinks he has. It was the contemporary belief among instrument makers, for example, that Chester Moor Hall's attempts to retain his idea for the achromatic lens failed because of his ignorance of subcontracting practices among opticians.

Upton's account of the day has Crosfeild, Palmer and himself walking along Fleet Street after they leave Bell Yard. While we are treating Upton's record as suspicious on many counts, Fleet Street is the most plausible route. They turn left up Fetter Lane and may use Pemberton's Row to cut through to Great New Street. If so, they pass the site of the Royal Society's Repository, which backs on to Pemberton's Row at the northern limit of the Crane Court

[64] J.A. Bennett, 'Shopping'.

premises sold by the Society in 1782.[65] The Repository had housed the wind-gun Wilkins had presented in 1663. Their route has also taken them fairly close to the premises of George Adams, on the southern side of Fleet Street, the firm that had supplied George III with his own air-gun.

The first stop we know of is at the shop of the brass-founder George Penton, at 32 New Street Square. When the trio enter, the clerk calls Penton's journeyman John Dowding down to the 'counting-house', as Dowding calls it. Dowding finds there are three men he does not know, standing waiting for him: one is tall and another is lame. Upton, who does most of the talking, begins by asking Dowding whether he can make a tube of precise dimensions – three feet long, outside diameter seven-eighths of an inch, inside five-eighths, brass thickness one-eighth of an inch: 'it was to be quite perfect, and the inside was to be quite a smooth cylinder'.[66] The visitors ask Dowding for a price, he says he cannot say – not even to within a few shillings? – no, says Dowding, that's a matter for his master and Mr Penton is not in. Dowding then shows them a piece of tube, which the visitors find appropriate for the outer diameter, but not the inner: the brass is not sufficiently thick, the inner bore must be smaller. Dowding is asked again about the price, but again he declines to say. This, he tells them, is an 'out-of-the-way job', he would have to make special tools, one to draw the tube on, another to smooth the inside. So the tube would be expensive.

This emphasis on the dimensions of the tube is clearly related to what Crosfeild has explained to Upton back in Bell Yard about the strength required for the magazine of an air-gun. Compressed air, Crosfeild has told him, exerts a great force and requires a thickness of metal that for a tube is, in Dowding's words, 'out-of-the-way'. It seems to have been assumed by the Privy Council and the court that the tube they wanted was for the barrel of the gun, and therefore it had to be uniform and smooth, but that does not explain the emphasis of the gauge of brass. This is the tube where the air is compressed: it has to be regular and smooth for the close-fitting piston.

Dowding suggests it might help if they tell him what the tube is for, but Upton says this is a secret, and the others agree. Dowding has decided that he does not want the job and tells his visitors that it is not worth his while taking it on and he is already too busy. Upton then produces a tube he had previously bought at the same shop. He wants to return it, because it will not serve the purpose. This may well be the original magazine that Crosfeild has judged too

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[65] J.A. Bennett, 'Wren's last building?,' *Notes and records of the Royal Society of London*, 27 (1972): 107-18.

[66] *Trial*, p. 36.

slight for the job.[67] Upton gives it to Dowding and the clerk, whose name is Mason, gives Upton a refund of ten pence. With that the trio leaves Penton's shop and head for New Street to continue their journey eastwards.

We learn some further small things about the brass-founding trade from the visit. Clearly Dowding thinks that charges have nothing whatever to do with him, but only his master. He will not be drawn in the slightest, beyond saying that an 'out-of-the-way' tube will be expensive. When asked in court whether he might have proposed some idea of the charge – 'a guinea, five guineas, or ten guineas?' – his reply was 'Being a journeyman I could not tell'.[68] More importantly, we learn that there was lacquering on the premises and that it was done by women. Lacquering suggests that, perhaps not complete items, but at least components were being finished at this brass-founder's. The defence seem to have been pursuing this topic as the testimony of a woman lacquerer might have shown that not everyone stayed in the 'counting-house'. Lacquering, Dowding explains, was carried on in a separate room; it would have been important to keep dust to a minimum. In fact no such testimony was offered.

From New Street Square it is scarcely any distance along New Street to Shoe Lane. As Palmer would explain in court, and as maps from the period confirm, 'There are two or three streets there that are called New-street, and New-street-square'[69] and on the way out of this confusion he has, as he would put it, 'a natural occasion to stop'.[70] The others go on without him, Upton saying that they will call next at the shop of the brass-founder Thomas Bland, at number 40. Upton and Crosfeild enter the shop, but do not stay for long, though long enough for Bland to notice that one of them is lame. Bland is not at all interested in the work – whether it is a tube or a barrel. Eight months later, when he will be asked to recall these events before the court, he will refer to both a barrel and a tube, though he seems to be confused in thinking that this was like a clock barrel. Whatever it is, it is not his 'line of business': 'if they wanted a barrel they must apply to the clock-makers, or if they wanted a tube they must apply to those that draw tubes'.[71]

Upton and Crosfeild leave after only a few minutes and head for Snow Hill. This is getting discouraging. Soon after they have gone, Palmer reaches Bland's shop and is told they were 'gone down the lane', so he follows them

[67] Upton produced a brass tube before the Privy Council and it was eventually used as evidence in the trial; it may well have been the other tube he showed to Crosfeild in Bell Yard, i.e. the intended barrel.

[68] *Trial*, p. 39.

[69] Ibid., p. 62.

[70] Ibid, p. 63.

[71] Ibid., p. 43.

and catches them up in Shoe Lane. Almost every likely route from Shoe Lane to Snow Hill – Stonecutter Street, perhaps, then Bear Alley or Goose Alley – goes through the Fleet Market, where George Higgins, in the shop of the chemist and apothecary, could not have suspected that events that would turn his life upside-down were taking place close by. Off Snow Hill is Cock Lane and the shop of the brass-founder Joseph Flint.[72] They arrive there not long after dinner, at least as reckoned by Flint's routine, and are met by the apprentice James Hubbart, who calls his master. Again Upton takes the lead, but here he pursues a slightly different line. Perhaps since the 'out-of-the-way' is problematic, Flint is asked to begin with something familiar, a long pistol barrel He shows them the barrel for a musketoon, but is told that the tube must not be closed off at the end. The dimensions are recited again – only the cross section this time, not the length – and Flint is told that if he casts and bores the tube, his visitors themselves will be able to finish it. That sounds like a remark that, of the three, only Upton can have made.

Flint at least is interested in the work, but he explains that he will need a pattern to do the casting. By this he means a model, from which he can prepare a mould. Might a rocket-case do for a model? – yes, says Flint, if the end is plugged. Someone asks how long the job will take – about three days. As they leave, Flint notices that one of the men – the one who has done most of the talking and who 'seemed to be the principal'[73] – is lame. It is unfortunate for Upton that his infirmity singles him out; he is the one everyone remembers.

At last a brass-founder seems willing to make the tube and the next step is to commission a pattern. A turner could make one in wood and Upton knows someone nearby in Bartholomew Close, just beyond St Bartholomew's Hospital; Palmer also knows him. Like the three associates, he is a member of the London Corresponding Society. His name is John Hill. Hill agrees immediately that he will do the job. Again Upton introduces the problem, but although Hill agrees to do the work, he has difficulty understanding Upton's verbal account, so a sketch is made. Hill provides a pen and ink, and piece of scrap paper which was formerly a sign saying 'This house to let enquire within'.[74] They work on the back of this sheet, and all three of Upton, Crosfeild and Hill (but not Palmer) contribute to the emerging sketch. Crosfeild adds the dimensions, so maintaining his emphasis on the thickness of the tube.[75]

[72] There is some confusion in the record over the involvement of a brass-founder Michael Bannett with this shop, Ibid., p. 27.

[73] Ibid., p. 42.

[74] Ibid., p. 69.

[75] In introducing the case for the Crown, the Attorney General said that 'that part of the writing upon the paper, which states the dimensions of the instrument, is in the hand-writing of Mr. Crossfield'. Ibid., p. 28.

But it is Upton who places the order with Hill, it is to Upton's address that the work will be delivered (which Hill will do about three days later) and it is Upton who will pay.

During the course of this discussion, Hill asks Upton what the work is for and is told that it is 'for something in the electrifying machine way'.[76] Is Upton trying to deceive him with a downright lie? Would Hill be so uninformed about electrical machines that he could imagine that a component such as the long tube under discussion could require such precision in its manufacture and dimensions? As Hill would later recall, 'It was to be quite straight, like a round ruler'.[77] Or is Upton, who we know is inventive and resourceful in his answers, deflecting the question with an oblique, rather than an untruthful, response? He has an electrical machine at home, which he made himself, though certainly from parts commissioned from other artisans, and which he shows 'as a curiosity'. He is now seeking to acquire another item of experimental curiosity, something which is certainly in the same 'way' as his electrical machine. It is worth noting that Mr Gurney, counsel for Crosfeild, makes an observation along these lines in his final submission to the jury. He too sees Upton's ambition within the regular scope of experimental philosophy:

> … it was not so very remarkable that Mr. Upton should be going to a brass-founder's, or that he should be going to a turner's, for the purpose of ordering any instrument to be constructed which was not in his ordinary business as a watch-maker, because it has been proved that he was, likewise, an ingenious mechanic in other branches; that he had in his shop an electrical machine of a curious construction, of his own invention, that he was extremely proud of it…[78]

Developing the design for Upton's second curious apparatus of experimental philosophy involves an exchange between an inventive mechanic ('an artist and mechanic' as he styles himself), a physician who certainly sees himself as something of an experimental philosopher, and an artisan who will supply the out-of-the-way components. The creative process is advanced, not quite on the proverbial back of an envelope, but something very close. Drawing seems to be essential to this process, and without a drawing the artisan cannot get to

[76] Ibid., pp. 69-70.

[77] Ibid., p. 70.

[78] However Gurney does not take Upton's specific remark to Hill about 'something in the electrifying machine way' in the general sense I have suggested: he continues, '… and you observe when he was asked by Hill the purpose for which the models were wanted by him, he said they were for the purpose of an electrical apparatus'. Ibid., pp. 232-3. The prosecution (the Attorney General) said simply that the instrument was 'falsly represented' as an electrical machine, but that is the construction to be expected for their argument, Ibid., p. 279. For the electrical machine, see also National Archives, TS 11/547.

grips with the problem. It would be interesting to find this drawing – the combined efforts of three men, on the back of a discarded 'to let' sign. There is a tantalising promise of a copy in the prosecution brief at the National Archives, but although a large space has been left for the copied drawing, frustratingly it is still blank: the intended copy was never made.[79]

In the absence of the drawing itself, we at least have an independent and expert assessment of it – the view of another artisan, Harvey Walklate Mortimer, a well-known gunsmith in Fleet Street with thirty years in the business. He was enjoying the limelight in court, consulted as he was as the expert for the Crown, announcing the kinds of guns that he supplied, explaining how he would have improved on the design of Upton, clapping his hands together to demonstrate the sound of an air-gun in a confined space.[80] At one point the Lord Chief Justice had to tell him to 'Be content just to answer the questions'. He let everyone know that he had sold a walking-stick air-gun to the king, 'sent as a present to the Dey of Algiers'. So, George was aware of walking-stick guns as well as those charged by condensing engines.

Mortimer seems to have been torn between wanting to dismiss the ignorant efforts of these unskilled designers, and relishing the drama of pronouncing on a fearful weapon. He immediately related the wooden patterns to the magazine, not the barrel, though despite Crosfeild's efforts, the inner diameter was still too large. But such was Mortimer's disdain for the drawing that he found himself saying that he could not relate it to the patterns made by Hill. This was not at all what was wanted by the prosecution, since it jeopardised the link between the drawing Crosfeild had helped to produce and the patterns for the gun. Crown counsel had to help Mortimer out by suggesting that, despite the incompetence of the drawing, the patterns could still be made 'with some verbal assistance by way of directions'.[81] Mortimer seemed only just willing to admit this, when the intervention of the Lord Chief Justice helped him along:

Lord Chief Justice Eyre. The question is whether with verbal directions the two pieces of wood you have in your hand might have been formed from the hint given from that drawing?
A. Very indifferent drawings will do with verbal directions.
Lord Chief Justice Eyre. Do you suppose that with verbal directions these two pieces of wood might have been formed from the hint given by that drawing?
A. I have no doubt of it.[82]

79 National Archives TS 11/547.
80 *Trial*, pp. 135-41.
81 Ibid., p.138.
82 Ibid., pp. 138-9.

Mortimer had eventually landed somewhere in the vicinity of where he should have been, but the drawing, to which Crosfeild had contributed only a part, was now only a 'hint' of the model for the instrument. The following day, counsel for Crosfeild took the opportunity to mention the uncertainties of even 'a scientific man, who wished to shew us last night an ostentatious sample of his scientific knowledge unnecessary for the occasion'.[83]

So what part did the drawing play in this example of mechanical invention? Hill had found the verbal description unintelligible without a drawing. A drawing is prepared collaboratively by Upton, Crosfeild and Hill himself, and Hill is able to make the required patterns from this drawing. But when Mortimer examines it, he can see no independent connection between the drawing and Hill's work: 'it could not have been a drawing of it without verbal explanations'.[84] It seems that at least in this instance the drawing was essential to invention, but could not fully represent the outcome – indeed to an outsider, it seemed not to represent it at all.

Walking the route today, in a casual, conversational manner, takes only about 50 minutes. All the streets where the trio stopped – Bell Yard, New Street Square, Shoe Lane, Cock Lane and Bartholomew Close – survive in roughly their eighteenth-century shapes, even though almost all the contemporary buildings have gone. Upton's lameness may have slowed them down and we should allow time for the conversations in the shops, but the whole episode cannot have taken much more than an hour and a half.

Here is an episode in the history of experimental philosophy and mechanical invention but, by any science-historical standard, it was a casual occurrence of no significance and no consequence. Even in the context of everyday life it seemed at the time entirely contingent and inconsequential. As Palmer put it in court:

> Mr. Crossfield and I were going somewhere upon some business together; it was merely an accidental business Upton's going with us.
>
> …
>
> At the time these things were going on, I had no idea that they were of a nature that I should be called into a Court of Justice to give evidence upon, and therefore I considered them as mere trivial things.[85]

It was, as it turned out, a fateful episode for the lives of a number of people – for Crosfeild, Lemaitre, Higgins and Smith, and for their families. Smith's health was broken in Newgate. Lemaitre's mother died of anxiety as her young

[83] Ibid., p. 164.
[84] Ibid., p. 168.
[85] Ibid., pp. 57-8.

son lay in prison awaiting trial for high treason. The instigator Upton suffered along with the others, losing his business and his livelihood.

For the history of science, the unimagined sequel to the afternoon of 8th September has given us an account of 'trivial things' that would otherwise have gone unrecorded. How can we use such an unusual record? Had, say, the ingenious mechanic Jesse Ramsden accompanied the real Joseph Banks on what was described in court as 'all the peregrination in the different streets to the different brass founders,'[86] we would probably feel more secure in drawing conclusions we would value from such an account. But the tall man and the lame man who actually made the peregrination, with a friend of one of them tagging along, have no assumed claim to our attention. The resources they were using, however, in the complex of London workshops were exactly the same as those that would have been available to anyone pursuing some new invention; indeed with Upton involved there was more understanding of the workings of the trade than would be the case for most philosophical shoppers. The record gives us insights into the variety and differentiation within the mechanical trades of artisanal London, as well as the engagement of at least sections of that world with experimental philosophy. Normally we become aware of such ambitions through the offer of an invention or modification for consideration by a recorded institution or meeting, such as the Royal Society. Here we glimpse ambitions taking shape.

If the question of triviality is an issue for historians today, it was under more urgent examination at Crosfeild's trial. If we shift our attention from the philosophical to the temporal, this would not have been a trivial episode had it been a critical step in a successful plot to assassinate the king. Defence counsel sought to represent the events of 8 September as casual and incidental. Palmer's testimony was especially helpful to them here, as was, for example, the time spent haggling about prices. Even Palmer's 'natural occasion to stop', followed by his efforts to catch up with the other two, could be presented as inappropriate to any deadly intent, while the setting Palmer gave to the whole episode, begun simply by his needing to collect a repaired watch, was problematic for the prosecution.[87] But why would Crosfeild have taken any part in the perambulation, if it were only an 'accidental business' of 'trivial things'?

[86] Ibid., p. 74.

[87] It might also be thought problematic that if Crosfeild's part in the perambulation was incriminating, why not Palmer, who faced no charge? Palmer was needed for the prosecution case, since only he was able to identify Crosfeild, as none of the artisans knew him. Accordingly, Palmer was called as a witness by the prosecution, which put them in a difficult position when they found themselves trying to discredit his evidence, and the judge pointed out to them that discrediting their own witness would be very damaging to a case that depended in other respects on his credit.

Why did he care at all for the design of the instrument, or be moved to contribute to the drawing made in Hill's shop? Summing up, the Lord Chief Justice struggled with this question: 'to be sure it is not absolutely impossible that when an aukward [sic] sketch was making, a man who was not immediately concerned in it might take a pen and make a stroke',[88] but the time and effort still seemed to denote some commitment. Commitment to what? It was not clear that everyone could imagine experimental philosophy bearing this weight. If we struggle to give the pop-gun a deserved place in the world of experiment and invention, it is worth remembering that, at the time, locating it there was exactly what was needed to render it inconsequential. It would then become, as counsel for Crosfeild put it, 'a mere matter of mechanical curiosity'.

Primary sources

Adams, George, *Lectures on natural and experimental philosophy* (London: R. Hindmarsh, 1794).

Adams, George, *Lectures on natural and experimental philosophy* (London: W. & S. Jones, 1799).

Birch, Thomas, ed., *The history of the Royal Society of London* (London: A. Miller, 1756-7).

Boyle, Robert, *New experiments physico-mechanicall, touching the spring of the air* (Oxford: H. Hall, 1660).

Boyle, Robert, *New experiments and observations touching cold* (London: John Crook, 1665).

Boyle, Robert, *New experiments physico-mechanical, touching air* (London: Richard Davis, 1682).

Crosfeild, Robert Thomas, *Dissertatio medica inauguralis quaedam de arthritide genuina complectens* (Leiden: Frates Murray, 1791).

Crosfeild, Robert Thomas, *Remarks on the scurvy* (London: J. Ridgway, 1797).

Digby, Kenelm, *Two treatises in the one of which the nature of bodies, in the other, the nature of mans soule is looked into in way of discovery of the immortality of reasonable soules* (Paris: Gilles Blaizot, 1644).

Ferguson, James, *Syllabus of a course of lectures* (Edinburgh, 1768).

Gurney, Joseph, ed., *The trial of Robert Thomas Crossfield* [sic] *for high treason… Taken in short-hand, by Joseph Gurney* (London: Martha Gurney, 1796).

Grew, Nehemiah, *Musaeum Regalis Societatis* (London: W. Rawlins, 1681).

Lemaitre, Paul Thomas, *High treason!! Narrative of the arrest, examinations before the Privy Council, and imprisonment of P.T. Lemaitre* (London: J. Smith, 1795).

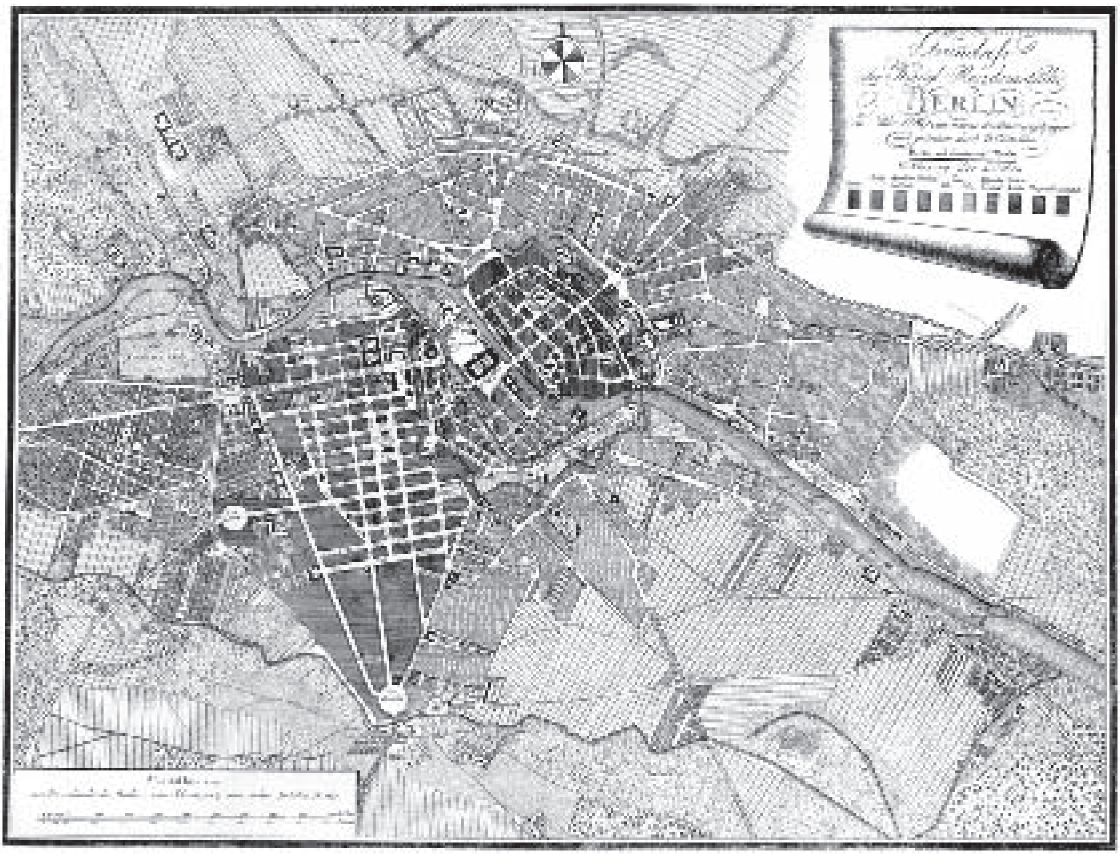
Martin, Benjamin, *The young gentleman and lady's philosophy* (London: W. Owen, 1772).

More, Henry, *The immortality of the soul* (London: William Morden, 1659).

More, Henry, *Remarks upon two late ingenious discourses* (London: Walter Kettiby, 1676).

Smith, John, and George Higgins, *Assassination of the King! The conspirators exposed* (London: J. Smith, 1795).

88 *Trial*, p. 315.



Map of Berlin in 1786, from Friedrich Nicolai, *Beschreibung der Königlichen Residenzstädte Berlin und Potsdam aller daselbst befindlicher Merkwürdigkeiten und der umliegenden Umgebung* (Berlin: Nicolai, 1786, 3 vols.), vol. 1: enclosure.

ILLUSTRATION 25

Apothecary's shops, laboratories and chemical manufacture in eighteenth-century Germany

Ursula Klein

In a memoriam published in the *Chemische Annalen* in 1786, Lorenz Crell, editor of this chemical periodical and professor of theoretical medicine and *materia medica* at the University of Helmstedt, celebrated the apothecary and chemist Andreas Sigismund Marggraf (1709–1782) as the 'renewer' of 'European chemistry'.[1] 'Marggraf's name is too famous, his merits for chemistry too great,' he observed, 'for him to become any better known among Germans'. The apprenticed apothecary Marggraf, who never earned a university degree and ran his father's apothecary's shop for almost twenty years, had been director of the chemical laboratory of the Berlin Academy of Sciences since 1753 and director of its Physical Class since 1760. By the end of his life he was one of the most renowned men in Europe, and his 'writings were studied by every chemist'.[2] Marggraf's career was by no means a singularity. Among the leading German chemists in the 1780s – J. C. Wiegleb (1732-1800), M. H. Klaproth (1743-1817), L. Crell (1745-1816), J. F. Gmelin (1748-1804), J. F. Westrumb (1751-1819), F. C. Achard (1753-1821), J. F. A. Göttling (1753-1809), F. A. C. Gren (1760-1798), and S. F. Hermbstädt (1760-1833) – Wiegleb, Klaproth, Westrumb, Göttling, Gren and Hermbstädt were apprenticed and practising apothecaries, and Wiegleb and Westrumb remained apothecaries throughout their professional career. Around half of the 100-200 Germans carrying out chemical investigations and acknowledged as 'chemists' in the 1780s became acquainted with chemistry as pharmaceutical apprentices and practising apothecaries.[3] The interconnectedness of pharmaceutical art and chemistry in eighteenth-century Germany also becomes manifest through the analysis of the readers of and contributors to professional periodicals such as the *Chemische Annalen*.

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[1] Lorenz Crell, 'Lebensgeschichte Andreas Sigismund Marggraf's, Directors der physikalischen Klasse der Königl. Preuß. Akademie, Mitglieds der K. Akademie der Wissenschaften zu Paris und der Churfürstl. Maynzischen zu Erfurt,' *Chemische Annalen für die Freunde der Naturlehre, Arzneygelahrtheit, Haushaltungskunst und Manufacturen*, 1786, part 1: 181–192, p. 181. All translations are my own.

[2] Crell, 'Lebensgeschichte Marggraf's,' p. 182.

[3] See Karl Hufbauer, *The formation of the German chemical community (1720–1795)* (Berkeley: University of California Press, 1982), pp. 53–61, p. 145.

Among the 564 German subscribers to Crell's *Chemische Annalen* between 1784 and 1789, 260 (46%) were apothecaries, and among its German contributors more than 40% were apothecaries as well.[4] Apprenticed and practising apothecaries were also the most active contributors to Crell's journal, with single contributors publishing up to sixty eight papers during the five-year period from 1784 to 1789.[5] Many eighteenth-century German chemists were also involved in other arts and crafts such as mining and metallurgy, the manufacture of porcelain, and dyeing and bleaching, but by far their most extensive artisanal occupation was pharmacy.[6]

Historians of science have offered two main explanations for the existence of apothecary-chemists in eighteenth-century and early nineteenth-century Germany and elsewhere in Europe. In the older literature the focus was on the individual apothecary who became famous as a chemist, and the explanans of his professional career was outstanding genius. Newer literature has highlighted the cultural and political conditions of such careers. The common denominator of the two approaches has been the assumption that pharmaceutical art and chemistry were two separate practices and cultures by the end of the eighteenth century, and that apothecaries had to leave their art to become elevated to the separate world of the science of chemistry. Karl Hufbauer, for example, stated that support for the natural sciences increased in Germany during the eighteenth century, and that the 'new utilitarianism was motivating fresh support for the republic of letters' scientific wing'.[7] Utilitarian beliefs held by rulers and academicians opened up access to academic institutions for apothecaries and other artisans who possessed useful knowledge and technical expertise. Hufbauer further characterised the pharmaceutical art as a 'realm of recipes,' and apothecary-chemists as men who 'sought to transcend the realm of recipes'; in his view there was 'a gap between compounding medicines and pursuing chemistry'.[8] This 'gap' could be bridged, according to Hufbauer, 'because latent energies in the pharmaceutical profession were released by

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4 Hufbauer, *German chemical community*, pp. 86–88. Information about subscribers for the period 1784–1789 was given in Crell's journal.

5 The most active contributor (with sixty eight papers) was the apothecary and chemist Johann Friedrich Westrumb, who first administered the *Hofapotheke* in Hanover and was then lessee of the *Ratsapotheke* in Hamelin until his death in 1819. Westrumb performed all experiments he reported in his publications in his pharmaceutical laboratory. In addition he was mining commissioner, member of the Chamber of Commerce of Hanover and a chemical entrepreneur who attempted to establish commercial bleaching with chlorine from 1789–90. Hufbauer, *German chemical community*, p. 203.

6 For an overview on additional artisanal occupations of eighteenth-century German chemists see Ursula Klein, 'Technoscience avant la lettre,' *Perspectives on science*, 13 (2005): 226–266.

7 Hufbauer, *German chemical community*, p. 147.

8 Hufbauer, *German chemical community*, p. 55, p. 56.

state intervention in recruitment'.[9] In other words, only when the state had recruited, for instance, A. S. Marggraf as the director of the chemical laboratory of the Berlin Academy of Sciences was some miraculous 'latent' agency set free that transformed the apothecary into a chemist.

There is no doubt that utilitarianism was a strong incentive for the great esteem for apothecary-chemists and other sub-groups of artisanally trained chemists in the German Enlightenment public.[10] Nor is there any doubt that rulers and other powerful patrons played a significant role in the acceptance of skilled apothecary-chemists as members or even leading figures of scientific academies, and as professors of chemistry at universities and professional schools. Far from demarcating knowledgeable artisans trained in a system of apprenticeship from skilled savants educated at universities, and far also from separating authorship from handiwork, the German Enlightenment public, governments and patrons appraised and supported apothecary-chemists as well as other artisan-savants. But this socio-cultural context can hardly explain how owners of apothecary's shops and manufacturers of remedies became acquainted with the practice and theory of chemistry and how they became visible as skilled and knowledgeable chemists in the Republic of Letters. What kind of activities earned them the attention of a learned and supportive audience? What were the sites and resources of these activities? How did apothecaries' chemical investigations relate to pharmaceutical manufacture? As a matter of fact, A. S. Marggraf, like other apothecary-chemists, did not begin his career as a chemist after leaving the pharmaceutical business, but rather developed it alongside, and even in conjunction with that business, and J. C. Wiegleb and J. F. Westrumb remained apothecaries throughout their careers as learned chemists. Furthermore we may ask why apothecaries, who were trained in an artisanal system of apprenticeship and earned their living as merchants and manufacturers of remedies, merged so smoothly with other factions of chemists, for instance those who had earned a medical doctorate or were mining officials and assayers. Were there any aspects of the actual practice of apothecaries that were similar to other chemists' practice? Were there, in addition to individual talent, collective beliefs and state intervention, any collective material resources and elements of the practice and material culture of pharmacy that enabled apothecaries to carry out the same or similar

[9] Hufbauer, *German chemical community*, p. 55.

[10] On the variegated meaning of 'utilitarianism' in the European Enlightenment, see Lissa Roberts, 'Going Dutch: situating science in the Dutch Enlightenment,' William Clark, Jan Golinski and Simon Schaffer, eds., *The sciences in enlightened Europe* (Chicago: University of Chicago Press, 1999), pp. 350-288; Lorraine Daston, 'Afterword: the ethos of enlightenment,' Ibid., pp. 495-504.

kinds of chemical investigations as chemists working at other artisanal sites or at academic institutions?

I argue that Marggraf, like other German apothecaries who became renowned chemists, was a truly hybrid apothecary-chemist, and further, that an indispensable condition for the existence of the persona of an apothecary-chemist in the eighteenth and early nineteenth centuries was the high degree of correspondence between the material culture and practice of pharmacy and the material culture and practice of 'academic chemistry'.[11] Apothecaries did not have to bridge a huge gap between a rigid 'realm of recipes' and pharmaceutical routine, on the one hand, and a realm of innovative, pure chemical science, on the other. Rather, pharmaceutical art and academic chemistry overlapped in the eighteenth and early nineteenth centuries, in Germany and elsewhere in Europe.[12] Laboratories, pharmaceutical and academic-chemical, were the institutions where manufacture (in the case of pharmaceutical laboratories) or technological inquiry (in the case of academic chemical laboratories) and inquiry into nature were firmly entwined.

As a consequence of the introduction and acceptance of 'chemical remedies' during the seventeenth century, in the eighteenth century the pharmaceutical art was in a state of persistent change and innovation. There was hardly any recipe for the manufacture of chemical remedies that was not questioned, varied, improved or replaced by a new one. And there was hardly any chemical remedy that was not on the test-bench as a possible adulteration or a material that had not yet been identified unambiguously. Chemical techniques and instruments, connoisseurship of chemical substances and chemical analysis became significant tools for mastering problems of manufacture. Inversely, the solution of problems of manufacture provided insight into the 'nature' of

[11] In the following I use the term 'academic chemistry' for the eighteenth-century chemistry established at scientific institutions.

[12] Jonathan Simon has argued recently that the Chemical Revolution in the last third of the eighteenth century spurred a 'definite split' between chemistry and pharmacy, along with 'the rise of chemistry as a philosophical pursuit, increasingly independent of its practical applications;' Jonathan Simon, *Chemistry, pharmacy and revolution in France, 1777–1809* (Aldershot: Ashgate, 2005), p. 167, p. 7. His conclusion relies heavily on his focus on the rhetoric of the small group of French chemists associated with Lavoisier and the philosophical (or theoretical) dimension of chemistry. This conclusion is seriously challenged, among many other things, by the historical fact that long after the Chemical Revolution French apothecaries (or 'pharmacists') carried out chemical investigations, published papers in chemical periodicals such as the *Annales de Chimie*, and became professors of chemistry and members of the Institut (the Academy of Sciences). Simon explains the latter facts with the wishes of these men: they 'wanted to retain the image of the pharmacist as chemist;' they 'consciously chose to remain up-to-date chemists' (Simon, *Chemistry*, p. 130) – which not only debunks his own 'disciplinary approach' but also neglects French apothecaries' practice and the resources of their practice.

substances and their chemical transformations. The similarity of the material culture and techniques of manufacture in eighteenth-century pharmaceutical art to the material culture and experimental techniques of academic chemistry enabled apothecaries to shift their activities smoothly from pharmaceutical manufacture to the chemical investigation of nature, or to perform chemical analyses alongside pharmaceutical manufacture. Likewise, it enabled chemists performing experiments at academic chemical laboratories to shift from inquiries into nature to pharmaceutical and other technological inquiries.[13]

The goal of this essay is to illuminate the material culture of pharmacy in eighteenth-century Germany. As I cannot, for reasons of space, compare in any detail the material culture of eighteenth-century pharmacy with that of chemistry, I will merely allude to the latter, which is much better known among historians of science than the former. I understand the similarity of the material culture of eighteenth-century pharmacy to the material culture of chemistry established at academic institutions as only one, though very important, condition for apothecaries' frequent shifts from manufacture and technological inquiry to chemical inquiries into nature. The existence of such shifts is an essential part of my argument, but again, for reasons of space, I will not deal with this issue in this essay. Furthermore, I will not further substantiate in this essay my above assertion that the pharmaceutical art was internally highly innovative in the eighteenth century; nor will I analyse the specific forms of chemical knowledge that German apothecaries implemented in the manufacture of chemical remedies, or study in any detail the system of apprenticeship of German apothecaries, the institutional conditions of the persona of apothecary-chemist, and the relationship between apothecary-chemists and the majority of German apothecaries who never carried out chemical investigations beyond the pharmaceutically useful. The only supplement to my study of the material culture of pharmacy in eighteenth-century Germany is a brief description of the career of A. S. Marggraf in the first section of my essay to shed some light on the hybrid persona of the apothecary-chemist, which defies our common distinction between academic chemists and apprenticed apothecaries, or savants and artisans.[14]

[13] On such shifts see also Ursula Klein, 'Experiments at the intersection of experimental history, technological inquiry, and conceptually driven analysis,' *Perspectives on science* 13 (2005): 1–48; Ursula Klein and Wolfgang Lefèvre, *Materials in eighteenth-century science: a historical ontology* (Cambridge: MIT Press, 2007).

[14] For a broader overview see Ursula Klein, 'Apothecary-chemists in eighteenth-century Germany,' Lawrence M. Principe, ed., *New narratives in eighteenth-century chemistry* (Dordrecht: Springer, forthcoming).

Apothecary-chemists

Historians of science have studied eighteenth-century apothecaries and their art mainly in the context of the history of medicine. This approach is justified inasmuch as pharmacy was part of the medical system of a country and hence regulated to some extent by the medical system. Until the late eighteenth century, the German pharmacopoeias (or 'dispensatories,' i.e. official apothecary's books) and *Arzneitaxen* (i.e. official lists that regulated prizes of remedies) were written almost exclusively by medical doctors; prospective apothecaries also had to pass an examination by the medical doctors of the official *collegia medica* before they could become *Provisor*s, that is, administrators of apothecary's shops, or obtain a privilege to establish or buy an apothecary's shop of their own; further, town physicians and *collegia medica* regularly visited apothecary's shops to examine their supply with and quality of remedies.

In most eighteenth-century German states, apothecaries were not organised in guilds, as they were in France and Italy; instead, their rights and duties were regulated directly by governments. Privileged apothecary's shops, medical and pharmaceutical laws, pharmacopoeias, *Arzneitaxen* and the entire system of supervision by the *collegia medica* or town physicians were the most significant devices for state intervention into the pharmaceutical art. Nevertheless apothecaries' daily practice of purchasing natural simple drugs (*simplicia*), dispensing Galenic *composita*, and producing chemical remedies could not be externally regulated throughout by medical doctors and governments. It must also be studied historically in the context of the contemporary system of trade and manufacture and from the perspective of the actual practice, goals and interests of apothecaries, who were not only personnel of the medical system but also merchants and manufacturing artisans. The latter becomes particularly obvious in the fact that eighteenth-century German apothecaries manufactured chemical remedies in their own laboratories, and further sold and produced a plethora of commodities other than remedies, such as coffee, tea, tobacco, and spices, confectionery and syrups, pigments and tints, soaps, hair powder and pomades, wines, brandy and liqueurs.[15] It is also manifest in the fact that by the end of the eighteenth century several pharmaceutical laboratories became transformed into chemical factories.

Trade and manufacture required knowledge and skills that went far beyond medical expertise. As the debates about pharmaceutical apprenticeship in the second half of the eighteenth century show, most German apothecaries agreed

[15] Coffee, tea and tobacco were used as remedies in the seventeenth century, but became transformed into luxury articles in the eighteenth century; the same is true for some kinds of spices and spirit of wine.

that knowledge of botany and chemistry was particularly useful to their art.[16] There were, however, great local differences in botanical and chemical training. In eighteenth-century Germany, pharmaceutical apprenticeship was predominantly training in the apothecary's shop, and not all master apothecaries were able to teach their apprentices a broad range of botanical skills and chemical techniques. Berlin, where A. S. Marggraf was first apprenticed and later administered his father's apothecary's shop, was an exception in this respect, as the *Collegium medico-chirurgicum,* a Medical-Surgical School founded in 1723 for Prussian military surgeons, also offered courses in botany and chemistry to prospective apothecaries.[17] There were also differences in the extent of chemical manufacture and the equipment of apothecary's laboratories, especially between the provinces and the towns. As the apothecaries of the provinces often purchased chemical remedies from merchants ('*Materialisten*') – despite the fact that this was prohibited by law in most German states – and manufactured only a few different kinds of chemical remedies, their laboratories were presumably less sophisticated than those of town apothecaries; equipped with a furnace and a limited set of instruments and vessels mainly for distillation and decoction, they may have concentrated on long-standing chemical-pharmaceutical techniques.[18] The fact that the manufacture of chemical remedies was a well-established part of eighteenth-century pharmaceutical art implies that there were incentives – economical, social and legal – for all German apothecaries to build a laboratory and acquire chemical-technical skills and connoisseurship of chemical substances, but it does not mean that all of them manufactured the entire range of chemical remedies prescribed in pharmacopoeias and *Arzneitaxen*, let alone extended and refined chemical-pharmaceutical manufacture to inquiries into nature that went beyond the pharmaceutically useful. Nor does it mean that the majority of German apothecaries regularly read chemical publications, subscribed to chemical periodicals and became known as authors of chemical texts. Apothecaries such as A. S. Marggraf do not stand for the entire community of eighteenth-century German apothecaries, but only for the group of 'apothecary-chemists,' that is, the apothecaries who carried out chemical investigations into nature alongside chemical manufacture and who were also acknowledged as 'chemists' by

[16] On these debates and on pharmaceutical apprenticeship in eighteenth-century Germany see Klein 'Apothecary-chemists' and the primary and secondary literature quoted there.

[17] On the role played by this school in pharmaceutical training see Herbert Lehmann, *Das Collegium medico-chirurgicum in Berlin als Lehrstätte der Botanik und der Pharmazie* (Berlin: Triltsch & Huther, 1936).

[18] I infer this assumption from the contemporary complaints that apothecaries in the provinces often purchased chemical remedies from *Materialisten* and *Laboranten* as well as from complaints about apprenticeship.

the historical actors.[19] Occupied with both manufacture and learned inquiry into nature, technological inquiry and publication, these apothecaries were hybrid artisan-savants or, to use a somewhat anachronistic term, techno-scientists.[20] But it would be utterly mistaken to assume that the achievements of eighteenth-century apothecary-chemists rested predominantly on individual talent or on their wishes for higher social standing. The career of one Marggraf outlines a horizon of institutional possibilities that was constituted not least by apothecary's laboratories, their laboratory instruments, vessels and materials, and their common practice of manufacturing chemical remedies.

A. S. Marggraf was first apprenticed in his father's apothecary's shop, and in 1726 continued his apprenticeship at the Royal *Hofapotheke* of Berlin, administered at the time by the renowned apothecary-chemist Caspar Neumann (1683–1737).[21] His apprenticeship benefited from his training by C. Neumann in the laboratories of the *Hofapotheke* (see below) as well as from the newly established *Collegium medico-chirurgicum*, where he attended lectures on chemistry by C. Neumann and J. H. Pott. Once he completed his apprenticeship in 1731, he served a year as journeyman in an apothecary's shop in Frankfurt (Main) and another year in J. J. Spielmann's *Hirsch-Apotheke* in Strasbourg. In 1733 he proceeded to Halle, where he took lectures at the university on medicine and on chemistry by Friedrich Hofmann (1660-1742) and Johann Juncker (1679-1759). A year later he went to the famous mining town of Freiberg to learn mineralogy, metallurgy and assaying with the renowned Mining Councillor Johann Friedrich Henckel (1678-1744). Historians of technology and economics have pointed out the significance of travel and migration of journeymen for innovation and technological change in the arts and crafts in early modern Europe.[22] Pharmacy, which was a rapidly transforming art in the eighteenth century, received considerable stimulus from the system of service as journeymen and the exchange of knowledge and skill through travelling to many different sites of pharmaceutical and chemical manufacture, in Germany and abroad. Travelling provided prospective apothecaries with ample opportunity for higher learning of medicine, botany and chemistry. As there was no

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[19] See Klein, 'Apothecary-chemists'.

[20] For arguments that eighteenth-century chemistry can be conceived as an early form of technoscience see Klein, 'Technoscience'.

[21] On Neumann see Klein, 'Apothecary-chemists' and the primary and secondary literature quoted there.

[22] See, for example, S. R. Epstein, 'Craft guilds, apprenticeship, and technological change in preindustrial Europe,' *The Journal of economic history* 58 (1998): 684–713; Reinhold Reith, 'Technische Innovationen im Handwerk der Frühen Neuzeit,' in *Stadt und Handwerk in Mittelalter und Früher Neuzeit*, Karl Heinrich Kaufbold and Wilfried Reininghaus eds. (Köln: Böhlau, 2000), pp. 21-60.

formal regulation in Germany concerning journeymen's travel and the number of places they had to visit, there were great differences in this respect. But it is remarkable that many prospective apothecaries took the opportunity to travel during their time of service as journeymen to acquire knowledge and skills in mineralogy, metallurgy and assaying. Marggraf's outstanding analytical skills also rooted to some extent in his early courses on the assaying of metals.

In 1735 Marggraf returned to Berlin by way of the Harz mining district to become administrator (*Provisor*) of his father's apothecary's shop for the long period of seventeen years, until the shop had to be sold in 1752 because of his father's illness.[23] In the 1730s Henning Christian Marggraf, Andreas Sigismund's father, had become not only a renowned apothecary and assistant ('*Assessor*') of the Berlin Medical Board but also Berlin's second wealthiest apothecary.[24] His *Apotheke zum Bären* served as a model of an excellent apothecary's shop, and retained its standing even as late as the 1790s when the apothecary-chemist Martin Heinrich Klaproth took over as its owner.[25] The reputation of a good apothecary's shop depended not least on a well-equipped laboratory, along with a supply of a large range of chemical remedies.[26] Hence Marggraf found ideal conditions to amalgamate his life of an apothecary with that of a learned chemist. In 1738, that is, only three years after his return to Berlin, he had gained a reputation as a skilled and knowledgeable chemist and was elected an ordinary member of the Berlin Society of Sciences (which became the Berlin Academy of Sciences and Fine Literature in 1744). During his tenure as administrator of his father's apothecary's shop, from 1740 until fall 1752, when his father was forced to sell the shop, he published a total of fifteen reports on diverse chemical experiments – including experiments on phosphorus and its compounds (1740, 1743), the precipitates formed from solutions of metals (1745), the extraction of zinc from calamine (1746), the dissolution of silver and mercury in vegetable acids (1746), the analysis of a salt obtained from urine (1746), dissolution of zinc in vegetable acids (1747), the extraction of sugar from beets and other plants (1747), the preparation of pure silver (1749), on luminescent stones (1749, 1750) and the oils extracted

[23] In Prussia, the time of service as pharmaceutical journeyman normally lasted seven years, but this period could be shortened by visiting the Berlin *Collegium medico-chirurgicum*, attending lectures at universities or taking private courses in chemistry, biology, and medicine.

[24] See Georg Edmund Dann, 'Deutsche Apothekerfamilien: Die Familien Marggraf und Blell,' *Pharmazeutische Zeitung*, 82 (1937): 337–342.

[25] Klaproth purchased the *Apotheke zum Bären* in 1780. On the celebration of the 'former apothecary's shop of Marggraf' in the 1790s see anonymous, 'Fragmente aus dem Tagebuche eines Apothekers, ' *Journal der Pharmacie* 1 (1793): 40–47, p. 41.

[26] There are no documents of this laboratory left.

from insects (1749).[27] These experiments were either chemical analyses, or technological inquiries, or experiments that explored modes of chemical preparation and chemical properties of substances, that is, experiments in the vein of Baconian 'experimental histories' of substances.[28] All of them, including his most famous ones on the extraction of sugar from beets in 1747, were performed in the pharmaceutical laboratory that belonged to his father's *Apotheke zum Bären* on Spandauer Strasse 17. That is, Marggraf's career as a learned chemist did not begin after he left his pharmaceutical business but rather developed alongside, and even in conjunction with that business.

By coincidence, shortly after his father sold his apothecary's shop, Marggraf was offered the salaried position of the director of the new chemical laboratory of the Berlin Academy of Sciences.[29] The newly constructed academic building on Dorotheenstrasse 10, opposite the observatory of the Academy, which housed the chemical laboratory and a residence for the Academy's chemist, was ready for Marggraf to take up residence in 1754.[30] The instruments, vessels and materials that belonged to his former pharmaceutical laboratory moved with him to the new academic building. That is, there was direct material transfer of instruments and other materials from a pharmaceutical laboratory to an academic laboratory.[31] A similar direct transfer of equipment from a pharmaceutical laboratory to the laboratory of the Berlin Academy took place again in 1802 when the apothecary-chemist Martin Heinrich Klaproth succeeded Franz Carl Achard as the director of the academic laboratory; for from 1799 on Achard had used the Academy's laboratory as a 'sugar factory' to extract sugar from beets on a large scale, and part of

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[27] Marggraf's papers were published in the *Miscellanea Berolinensia* (in Latin) and the *Histoire de l'Académie Royale des Sciences et Belles-Lettres* (in French) of the Berlin Society of Sciences and Academy of Sciences, respectively (of 1744). A list of Marggraf's works is contained in: Otto Köhnke, 'Gesammtregister über die in den Schriften der Akademie von 1700–1899 erschienenen wissenschaftlichen Abhandlungen und Festreden,' in *Geschichte der Königlich Preussischen Akademie der Wissenschaften zu Berlin*, Adolf Harnack (Berlin: Reichsdruckerei, 1900, 3 vols.), vol. 3. Marggraf's papers also were republished in German: see Andreas Sigismund Marggraf, *Chymische Schriften*, (Berlin: Arnold Wever, 1761–67, 2 vols.).

[28] On 'experimental history' as a distinct style of experimentation that differed from 'experimental philosophy,' see Klein, 'Experiments at the intersection'; and Klein and Lefèvre, *Materials*.

[29] According to a letter by Marggraf, he had to move out of the apothecary's shop in fall 1852; see Georg Edmund Dann, 'Marggraf-Briefe,' *Geschichte der Pharmacie* 20 (1968): 20–22, p. 20.

[30] On this laboratory see *Archiv der Berlin-Brandenburgischen Akademie der Wissenschaften (ABBAW), Bestand Preußische Akademie der Wissenschaften (1700–1811)*: I–XIII–19 and I–XIII–20; Britta Engel, 'Das Berliner Akademielaboratorium zur Zeit Marggrafs und Achards,' *Mitteilungen* (herausgegeben von der Fachgruppe 'Geschichte der Chemie' in der Gesellschaft Deutscher Chemiker) 13 (1997): 3-12.

[31] *ABBAW*: I-XIII-20, folio 1, 7-8, 3-4.

this enterprise had been the removal of ordinary chemical instruments. In 1760 the Academy and the Prussian king further decided that Marggraf was to become the director of the Physical Class of the Academy. As director of the Physical Class, Marggraf was one of the most influential academicians, who also strongly supported experimental physics along with the establishment of a physical cabinet, which is not least expressed by the fact that after the establishment of the physical cabinet in 1765/66 he sometimes designated himself as the 'director of the '*Classe de physique expérimentale*'' rather than using its official title, '*Classe de Physique*'.[32]

The famous German apothecary-chemists such as A. S. Marggraf stood on top of an iceberg whose invisible part comprised the numerous apothecaries who manufactured chemical remedies and sometimes also carried out chemical investigations into nature without ever becoming known as chemists. Marggraf's achievements were embedded in a collective pharmaceutical practice that had established laboratories and implemented chemical instruments, techniques and knowledge during the seventeenth century, and that allowed shifts from the production of chemical remedies to chemical analysis and the experimental history of substances. They thrived in a historical constellation where state intervention, the accessibility of academic institutions by learned practitioners, the prospect of higher social standing and cultural interest in the experimental, useful sciences met with a pharmaceutical art that was internally innovative and whose material culture strongly overlapped with the material culture of the chemistry performed at academic sites. The latter issue will be discussed in more detail in the next section.

Pharmaceutical laboratories

Pharmacy was an old art or craft, which had led to the establishment of apothecary's shops in Europe in the late Middle Ages. Chemical operations such as distillation and decoction were performed in apothecary's shops long before 'chemical remedies' were accepted in the seventeenth century as a consequence of the iatrochemical movement in the vein of Paracelsus and his followers. Hence the pharmaceutical handicraft was by no means unprepared for the chemical innovations of the manufacture of remedies that were spurred by

[32] *ABBAW* I-XIII-1, folio 18. In the archival documents of the Berlin Academy of Sciences, the 'physical cabinet,' which sometimes was also designated 'cabinet of instruments' ('Instrumenten Cabinet') and 'cabinet of experimental physics ('cabinet de physique experimentale'), is first mentioned in January 1766 (*ABBAW* I–XIII–1). Unlike the chemical laboratory, the physical cabinet was not a site of experimentation but a room for storing instruments to be borrowed for performing experiments elsewhere.

sixteenth- and seventeenth-century physicians, alchemists and chymists. We know from medical edicts, pharmacopoeias and *Arzneitaxen* as well as from inventories of apothecary's shops, preserved pharmaceutical-chemical instruments and the books and papers published by apothecaries, that chemical remedies were broadly accepted in Germany around 1700. Especially the work of the historians of pharmacy Wolfgang Schneider and Erika Hickel provided ample evidence, based on their detailed analysis of German pharmacopeias and experimental reconstruction of their recipes, that chemical remedies were an accepted part of pharmaceutical art in early eighteenth-century Germany.[33] By this time the term 'chemical remedies' was as ubiquitous as the division of remedies into *simplicia* and *composita*, and the further division of the latter into Galenic *composita* and 'chemical preparations' or 'chemical remedies'. The eighteenth-century term 'chemical remedies' referred to a very broad range of different materials whose common denominator was that they were manufactured by means of chemical techniques such as distillation, decoction, digestion, sublimation, evaporation, combustion, calcination, fusion, dissolution and precipitation. They comprised simple vegetable oils, procured by the distillation of plants, as well as sophisticated mineral compounds that had been prepared by a long series of different chemical operations.[34] *Oleum Camphorae*, *Aqua Melissae*, *Acetum distillatum, Spiritus Tartaris, Spiritus Nitri, Crocus Martis, Flores Antimonii, Lac Sulphuris, Mercurius praecipitatus albus, Mercurius dulcis, Oleum Arsenici, Vitriolum Martis, Saccharum Saturni, Elixira composita, Laudanum opiatum* are only a few examples of hundreds of chemical remedies mentioned in German pharmacopoeias from the seventeenth century onward.[35]

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[33] See, for example, Erika Hickel, 'Der Apothekerberuf als Keimzelle naturwissenschaftlicher Berufe in Deutschland,' *Medizinhistorisches Journal* 13 (1978): 259-276; Erika Hickel, *Arzneimittel-Standardisierung im 19. Jahrhundert in den Pharmakopöen Deutschlands, Frankreichs, Großbritanniens und der Vereinigten Staaten von Amerika*, (Stuttgart: Wissenschaftliche Verlagsgesellschaft, 1973); Wolfgang Schneider, *Geschichte der pharmazeutischen Chemie*, (Weinheim: Verlag Chemie, 1972); Wolfgang Schneider, *Lexikon zur Arzneimittelgeschichte;* see also Mechthild Krüger, *Zur Geschichte der Elixiere, Essenzen und Tinkturen*, (Braunschweig: Technische Hochschule, 1968); Gabriele Beisswanger, *Arzneimittelversorgung im 18. Jahrhundert: Die Stadt Braunschweig und die ländlichen Distrikte im Herzogtum Braunschweig-Wolfenbüttel* (Braunschweig: Dt. Apothekerverlag, 1968).

[34] It should be noted that the eighteenth-century understanding of chemical remedies included many materials that are classified as 'natural' medicines today. The historical actors' criteria for their classification as 'chemical' were the site (i.e. in the laboratory) and techniques of preparation.

[35] I use, here and in most paragraphs that follow, the Latin names of remedies, which were also used in pharmacopoeias, because of the difficulty of translating the German names into English. For a comprehensive list of the chemical remedies mentioned in German pharmacopoeias from the sixteenth century onward see Wolfgang Schneider, *Lexikon zur Arzneimittelgeschicht: Sachwörterbuch zur Geschichte der pharmazeutischen Botanik, Chemie, Mineralogie, Pharmakologie, Zoologie* (Frankfurt a. M.: Govi, 1968–75, 7 vols.), vol. 3.

Equally ubiquitous were distinct rooms, designated 'laboratories', for the manufacture of chemical remedies, equipped with furnaces, distillation apparatus and numerous other chemical instruments, vessels and materials. The official medical and pharmaceutical edicts and pharmacopoeias of late seventeenth-century and eighteenth-century Germany took pharmaceutical 'laboratories' for granted. For example, the Brandenburg medical edict of 1698 ordered that the 'chemical remedies' ('*chimische Medicamenta*') must not be purchased from 'vagrants and laborants' but prepared and sold by apothecaries in their own 'laboratories'.[36] Furthermore, the term 'laboratory' also was commonly used in contemporary descriptions of apothecary's shops, autobiographies and letters of apothecaries as well as in apothecaries' publications that reported their chemical-pharmaceutical operations.[37] Today pharmaceutical museums exhibit a large range of chemical instruments and vessels used in eighteenth-century pharmaceutical laboratories, but unfortunately no such laboratory survived in its entirety. Apart from preserved instruments and vessels, our more detailed knowledge of eighteenth-century pharmaceutical laboratories relies on verbal descriptions, inventories, drawings, and the conclusions we can draw from the architecture of preserved seventeenth-century and eighteenth-century apothecary's shops. In what follows I present examples from these different kinds of historical sources.

Architecture

My first example comes from the *Ratsapotheke* of Quedlinburg, a town in the Harz region that had around eight thousand inhabitants in the mid-eighteenth century. *Ratsapotheken* were owned by towns and only leased to apothecaries. Until 1615 the *Ratsapotheke* of Quedlinburg, which was established in 1578, was a part of the town hall and then moved into another building (on Kornmarkt 8) bought by the town magistrate, where it is still located today (Ill. 26).[38] Inventories of the rooms in this new building, which were added to the leasing contracts from 1615 onward, allow the historical ground plan of the house to be reconstructed along with the location of the laboratory, which existed from

[36] The Prussian medical edict of 1693 is reprinted in Manfred Stürzbecher, *Beiträge zur Berliner Medizingeschichte: Quellen und Studien zur Geschichte des Gesundheitswesens vom 17. bis zum 19. Jahrhundert*, (Berlin: Walter de Gruyter, 1966), pp. 43–64, see p. 49.

[37] On eighteenth-century German apothecaries' publications, see Klein 'Apothecary-chemists' and the primary and secondary literature quoted there.

[38] The complete name today is *Adler- und Ratsapotheke*. The name Adlerapotheke was added after 1834 when the town sold the apothecary's shop; the address, Kornmarkt 8, has been preserved as well.

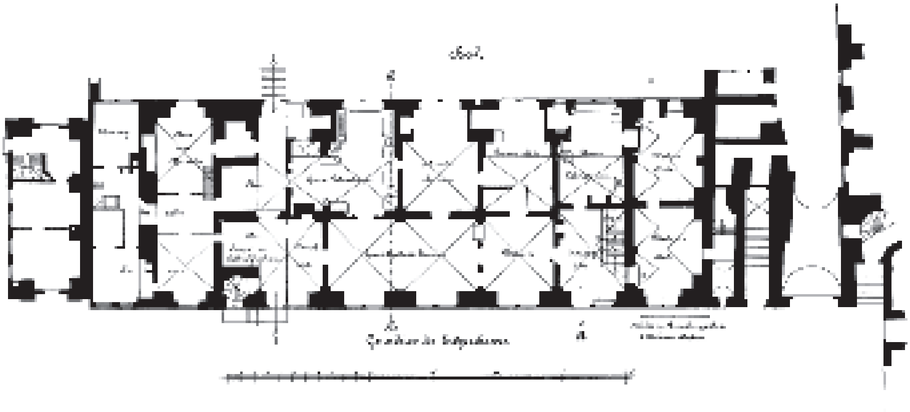
Ill. 26. Photograph of the (*Adler- and) Ratsapotheke* of Quedlinburg today, by the author.

1615 on.[39] In the second half of the eighteenth century this apothecary's shop was the site of apprenticeship of Martin Heinrich Klaproth and Johann Christian F. Liphardt (1758 or 1759-1805), who published additional information about this place.[40] The officine was located in the middle of the ground floor of the half-timbered front building, and the laboratory was established in a room of the side corridor, whose massive stone walls, stone floor and cross vaulting were especially suited for a laboratory (see illustration 26-27).[41] The private rooms of the apothecary were also on the ground floor. On the first floor was a room for storing materials (*Materialstube*) and another for confectionery (*Zuckerkammer*) as well as four large rooms (*Grosser Saal, Saal, Saalstube, Gastkammer*) and two smaller rooms (*Kammer, Gesellenkammer*) for housing distinguished guests to town and the journeymen, respectively; the apprentices

[39] See Konrad Grünhagen, *Über den Bau und die Einrichtung von Apotheken in alter und neuer Zeit*, (Würzburg: Konrad Triltsch, 1939), pp. 30-34; Hermann Lorenz, 'Die Ratsapotheke zu Quedlinburg,' (transcript of the *Quedlinburger Kreisblatt*, 1928, No. 178-181, Universitätsbibliothek Freie Universität Berlin).

[40] Georg Edmund Dann, *Martin Heinrich Klaproth (1743-1817)* (Berlin: Akademie-Verlag, 1958), p. 15, p. 142. Johann Christian Lüderitz Liphardt, 'Bemerkungen, Wünsche und Vorschläge für sämtliche Herren der Apothekerkunst; als ein Nachtrag zur moralischen Disziplin des Herrn Bindheim,' *Almanach oder Taschenbuch für Scheidekünstler und Apotheker*, 1784: 70-98, p. 73.

[41] This room with the cross vaulting still exists today and is still used as a pharmaceutical laboratory; of course, its equipment differs utterly from that of the seventeenth-century and eighteenth-century.



Ill. 27. Seventeenth-century ground plan of the Quedlinburg *Ratsapotheke*, reconstructed by Grünhagen; Grünhagen, *Apotheken in alter und neuer Zeit*, p. 31.

had to sleep in a large closet next to the laboratory on the ground floor. Two additional rooms for storing herbal drugs and for glassware were in the attic, and two rooms for storing distillates, wine, brandy and aqua vitae in the cellar. Well into the nineteenth century this kind of distribution of the rooms of an apothecary's shop over different floors of an entire building was quite common in Germany.[42] It was also quite common that the laboratory was located on the ground floor – which was especially convenient for supply with water and fuel – and in a room that had stone floors and vaulted ceilings. The many furnaces used in pharmaceutical and chemical laboratories at the time required protection from the danger of fire, for which purpose ceilings of stone, which had to be vaulted for static reasons, were much more suitable than flat ceilings constructed with wood. Alternatively, the laboratory was established in a separate building in the courtyard, which can be seen, for example, in the historical ground plan of the *Hirsch-Apotheke* in Potsdam, established in 1735 on Lindenstrasse, where it still exists today (on Lindenstrasse 48).[43] In the mid-eighteenth century, the laboratory of the Quedlinburg Ratsapotheke was equipped with six furnaces for distilling, two additional furnaces for the manufacture of spirits and a large chimney with a mantle. An inventory of 1754 also explicitly mentions instruments for cupellation, which supplemented the usual stock of instruments and vessels used for distillation, decoction, dissolution, precipitation and other 'wet' chemical operations or at lower temperatures.[44]

[42] See Grünhagen, *Apotheken in alter und neuer Zeit*.

[43] Grünhagen, *Apotheken in alter und neuer Zeit,* p. 61.

[44] Grünhagen, *Apotheken in alter und neuer Zeit*, p. 79.

Instruments and vessels

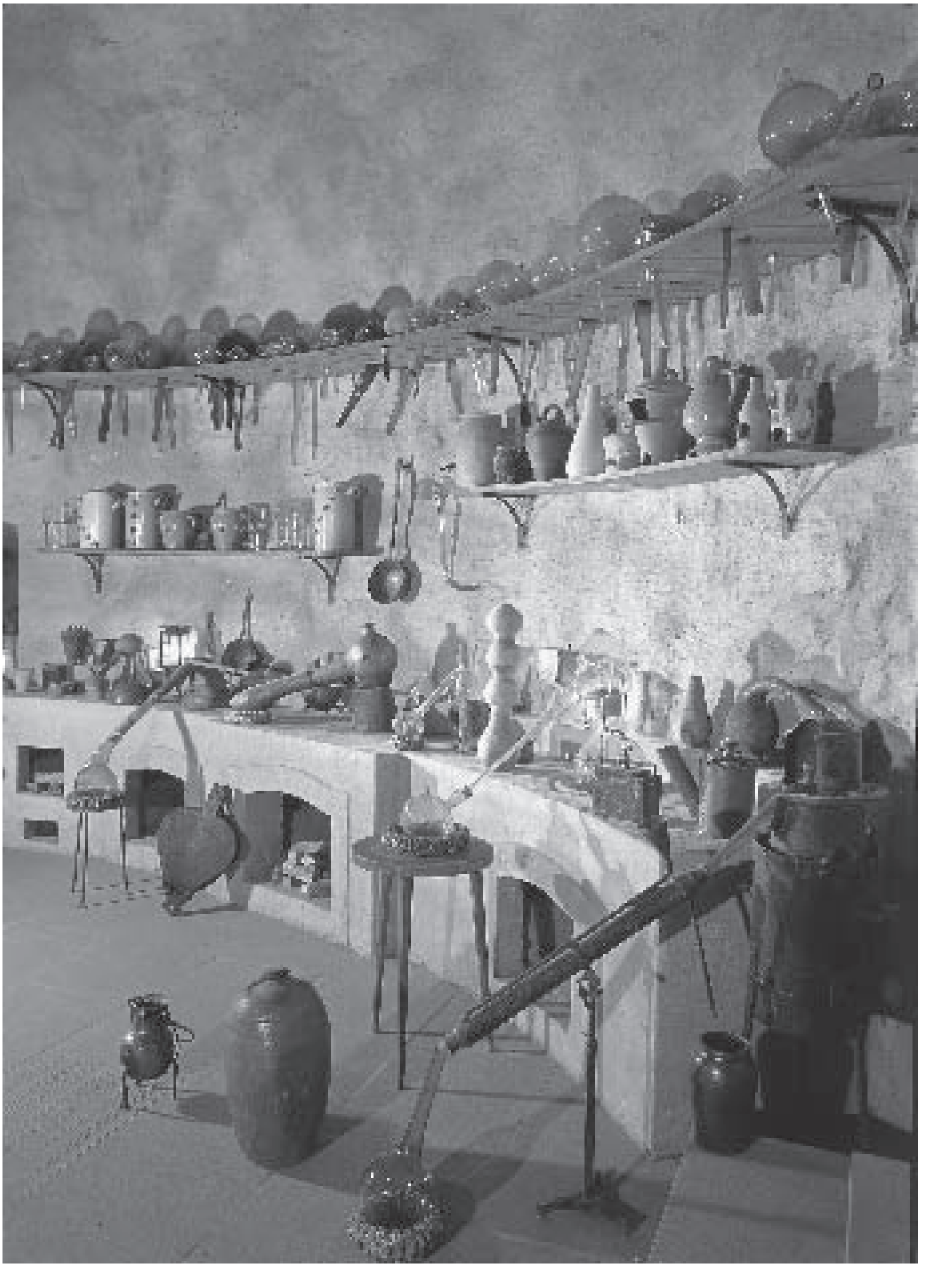
The German Pharmaceutical Museum (*Deutsches Apotheken-Museum*) in Heidelberg exhibits a collection of instruments that were normally in use in apothecary's laboratories from the seventeenth to the nineteenth centuries. In the photograph below (Ill. 28), which shows a part of the exhibition room, instruments and various kinds of vessels are distributed on two shelves and on the top of several large furnaces beneath the shelves.[45] The upper shelf contains glass retorts and other glass vessels that were used for distillation. On the shelf below we see a number of ceramic vessels and glass jars of different sizes and shapes as well as several small furnaces (in the foreground). On top of the large furnaces beneath the shelves, whose function is also indicated by a bellow, we see several complete distillation apparatus such as a retort connected with a receiver and an alembic, consisting of a matras or curcurbite (a vessel containing the material to be distilled), a capital or bolthead on top of the curcurbite and a receiver; there is also a stack of aludels for sublimation (pear-shaped pots of earthenware, open at both ends). In the foreground to the right stands another larger distillation furnace with a copper curcurbite on top of it, connected with a long cooler and a glass receiver.

All of these instruments and vessels used in eighteenth-century pharmaceutical laboratories are also familiar from depictions of eighteenth-century chemical instruments and academic-chemical laboratories, such as the one contained in Diderot's *Encyclopédie*.[46] Eighteenth-century apothecaries shared more than a few single instruments with academic chemists. The same types of furnaces, jars, retorts, receivers, alembics, pelicans, aludels, crucibles, balances, mortars, pestles, filters that academic chemists used in their laboratories were also used by apothecaries for making chemical remedies. More uncommon 'philosophical instruments', such as apparatus for the creation of and experimentation with kinds of air (or 'gases'), were not collectively accepted and further developed by chemists until the mid-eighteenth century; by the end of the eighteenth century, they, too, were sometimes implemented in the pharmaceutical laboratory. But as the historian of chemistry F. L. Holmes observed: 'Until late in the eighteenth century no major technological changes altered the character of the chemical laboratory as a material or social setting'.[47]

[45] It should be noted that these furnaces are not historical reconstructions of the kinds of furnaces used in eighteenth-century pharmaceutical laboratories.

[46] Denis J. Diderot and Jean LeRond d'Alembert, *Encyclopédie ou dictionnaire raisonné des sciences, des arts, et des métiers* (Stuttgart: Frommann, 1965, 35 vols.; first published 1751-1780), vol. 24.

[47] Frederic Lawrence Holmes, *Eighteenth-century chemistry as an investigative enterprise* (Berkeley: University of California Press, 1989), p. 18.



Ill. 28. Chemical-pharmaceutical instruments (17-19th cent.), courtesy of the *Deutsches Apotheken-Museum*, Heidelberg.

Even in the second half of the eighteenth century, balances and thermometers were the only precision instruments that were more widely distributed in chemical laboratories.

The laboratories of the Royal *Hofapotheke* in Berlin

Drawings, such as those of the Royal *Hofapotheke* in Berlin, offer further information about eighteenth-century pharmaceutical laboratories. The German *Hofapotheken* (court apothecary's shops) were either private apothecary's shops that supplied the court with remedies, or shops whose establishment and maintenance was financed and regulated by the sovereign. The Royal *Hofapotheke* in Berlin was of the latter type. It was founded in around 1598 by *Kurfürstin* Katharina, wife of *Kurfürst* Joachim Friedrich, to supply the Berlin-Brandenburg court, army and officials, as well as the poor with remedies, and it was located in a side corridor of the Berlin castle that had been built for the mint in 1585. As the rooms of the ground floor of this side corridor had barrel-vault ceilings, it was particularly suited to house both the mint and the two laboratories of the *Hofapotheke*. Around 1680 the mint was moved to another building, so that the rooms of the *Hofapotheke* could be extended over the entire ground floor. A ground plan from 1798 gives an impression of the arrangement of the rooms (Ill. 29).[48]

The existence of two laboratories, which was unusual at the time, speaks for some division of work, and the drawings seem to support this assumption. As can be seen in the drawings of the two laboratories (see illustrations 30 and 31), each laboratory had vaulted ceilings and stone floors and contained several different kinds of furnaces. Reports on these laboratories further mention that they were renovated around 1720 upon the request of Caspar Neumann, court apothecary from 1719-1737. On this occasion the laboratories were also equipped with an extraordinary novelty, namely a system of copper pipes that supplied them with running water and thus replaced the ordinary cooling casks used in distillation.[49] The main task of the large laboratory obviously was distillation on a comparatively large scale. The left part of the drawing shows large furnaces and large retorts, receivers, and alembics with a volume of more than ten litres. A series of even larger distillation apparatus, presumably made of copper, are presented on the right side. Such large distillation apparatus

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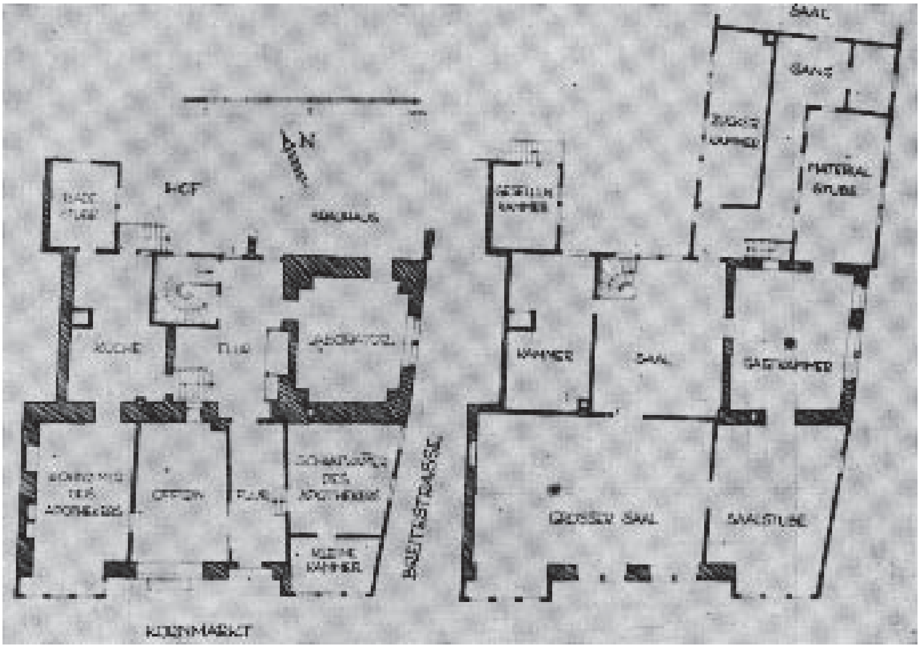
[48] See Johannes Hörmann, 'Die Königliche Hofapotheke in Berlin (1598–1898),' *Hohenzollern-Jahrbuch* 1898, 208-226; Albert Geyer, 'Die Räumlichkeiten der Königlichen Hofapotheke im Berliner Schloß,' *Hohenzollern-Jahrbuch* 1898, 227–230; Hermann Gelder, 'Zur Geschichte der (vormals Königlichen) Hofapotheke zu Berlin,' *Apotheker-Zeitung* 40 (1925): 1364-1367; Grünhagen, *Apotheken in alter und neuer Zeit*.

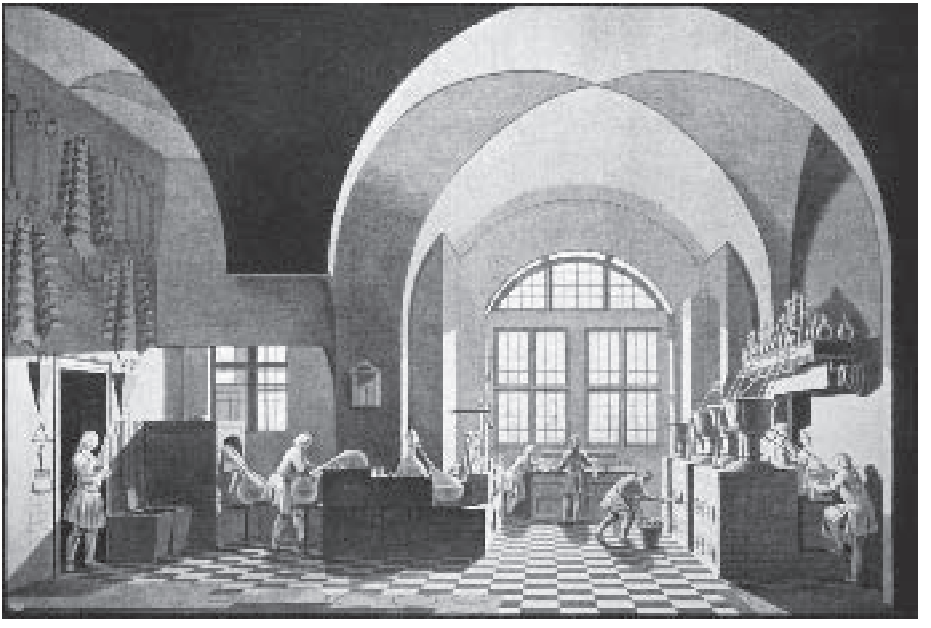
[49] See the memoriam of Neumann, 'Memoria Neumanniana,' by the medical Professor Anton Philipp Queitsch from 1737, a German translation of which is contained in Alfred Exner, *Der Hofapotheker Caspar Neumann (1683-1737)*, (Berlin: Triltsch & Huther, 1938), pp. 7-15. See also Hörmann, 'Hofapotheke,' p. 220. It should be mentioned that the castle as well as the *Lustgarten* had been equipped with a system of running water since 1580; see Wolfgang Ribbe (ed.), *Geschichte Berlins* (Berlin: BWV-Berliner Wissenschafts-Verlag, 2002, 2 vols.), 1, p. 327.



Ill. 29. Eighteenth-century ground plan of the side corridor of the Berlin castle that housed the *Royal Hofapotheke*, reconstructed in 1898 by Geyer, 'Hofapotheke,' p. 229.

were used only for the manufacture of comparatively inexpensive goods that could be sold on the local market in larger quantities, such as some kinds of distilled waters and vegetable oils; indeed, back in 1639, as a consequence of financial troubles during the Thirty Years' War, *Kurfürst* Georg Wilhelm had disbanded his distilling house on the *Werder*, ordering that the court apothecary must take over its business.[50] On a shelf affixed to the right wall there are also smaller distillation devices, among them many receivers and alembics. On the left side of the drawing we see apparatus for refluxing (consisting of two matrasses), bellows, and various pokers fixed to the wall above and beside the door. In the background two men are standing at a table, one of whom is in a pose of reading or thinking whereas the other seems to be performing some handiwork. The drawing shows a total of seven men, all dressed in gentlemanly fashion, except for the one heating the furnace; in the frame of the door we also see a woman. This number of men may appear astonishing, as an apothecary normally employed between one and three clerks and one or two

[50] Hörmann, 'Hofapotheke,' p. 215.



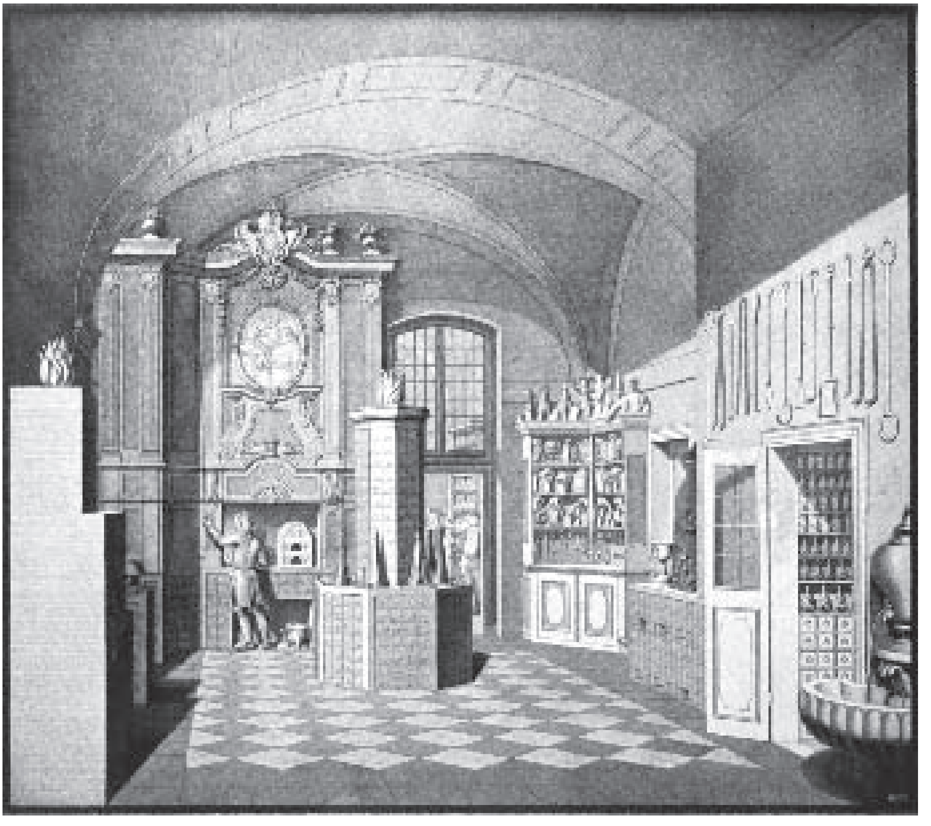
Ill. 30. The large laboratory of the Berlin *Royal Hofapotheke* (18th cent.), from Hörmann, 'Hofapotheke,' p. 220.

apprentices. But we know from an administration report by Caspar Neumann that in 1732 (the year of the report) around twenty men were working in the *Hofapotheke* – 'the many women excepted' – namely five to six journeymen (*Gesellen*), eight to nine apprentices (*Jungen*), one herbalist, and five men for grinding (*Stößer*).[51] At the time, the *Hofapotheke* dispensed, at no or minimal cost, remedies to the court, civil servants, bishop and clergymen, army, hospitals and orphanages, that is, to around 20,000 people by Neumann's account.[52] As the *Hofapotheke* also sold remedies to other people, it produced remedies on a larger scale than ordinary apothecary's shops at the time.[53]

[51] Caspar Neumann, 'Kurtze Nachricht von der Oeconomie und Verwaltung der Koenigl. Preuss. Hoff-Apotheken,' reprinted in Exner, *Caspar Neumann*, pp. 71-81, on p. 80. As to the women, Neumann wrote: '…der verschiedenen Frauens Leute, Wasch- und Schaur Weiber nicht zu gedencken'.

[52] Neumann, 'Kurtze Nachricht,' p. 74, and p. 76. See also Hörmann, 'Hofapotheke,' p. 220.

[53] Data about this are available for the 1790s. In 1790 Berlin had 150,803 inhabitants (See Ribbe, *Geschichte Berlins*, 1: 413), and there were 24 private apothecary's shops in Berlin (see Alfred Adlung, 'Alte Apothekerfamilien und ihre Apotheken,' *Pharmazeutische Zeitung* 73 (1928): 1453-1460). That amounts to an average of approximately one apothecary's shop for every 6,000 inhabitants of the city; however, the number of people who were actually supplied with remedies was presumably smaller as many could not afford to buy remedies from an apothecary.



Ill. 31. The small laboratory of the Berlin *Royal Hofapotheke* (18th cent.), from Hörmann, 'Hofapotheke,' p. 224.

The drawing of the small laboratory shows much smaller distillation vessels and further utensils, stored in and upon a closet in the background, as well as jars and vials stored in another closet with drawers, which is located in a small storage room adjacent to the laboratory. In the background is a preciously ornamented chimney along with a small assaying furnace for fusing and calcinating metals; two larger furnaces stand against the right and the left walls, and another large, octagonal furnace with a large tower, an 'athanor,' which was used for slow digestions, is located in the middle of the room. In the foreground to the right are a marble rinsing basin and a copper vessel for water supply, and there are also accessories for metallurgical work affixed to the right wall. Both the rinsing basin and the baroque chimney, which A. Geyer identified as an early work by the famous architect Andreas Schlüter, who reconstructed the entire Royal Castle from 1698–1707, still existed around 1900;

according to Geyer, who had seen both of them, the lower part of the chimney contained a large bellow along with an air shaft.[54] The more valuable equipment of the small laboratory, and the smaller size and greater diversity of its instruments manifest that it was a place for more sophisticated chemical-pharmaceutical operations. Here some hundreds of different kinds of chemical remedies may have been manufactured in small quantities by the Court Apothecary.[55] Apart from the fact that the Brandenburg medical edict ordered that chemical remedies must be prepared by a master apothecary, manufacture of a large number of different kinds of remedies required outstanding skills and chemical knowledge – hence it is not surprising that the drawing depicts only one man: the Court Apothecary.

Manufacture of luxury articles

Pharmaceutical laboratories were the site where apothecaries manufactured chemical remedies. But not only chemical remedies originated there. Apart from simple drugs and Galenic remedies, eighteenth-century German apothecaries sold a large range of commodities other than chemical remedies, such as coffee, tea, tobacco, sugar and confectionery, spices, wines and brandy. At some places the selling of wine and other alcoholic potions was a quite normal way to improve the income of apothecaries, although this was not always approved by the local authorities.[56] For example, around 1800 the town physician of Quedlinburg complained: 'In the apothecary's shop frequent meetings take place of several persons who are served with brandy (*Branntwein*) and also smoke tobacco. I must request that the officine no longer be allowed to be reduced to a brandy pub'.[57] Apothecaries' trade with luxury articles also entailed endless quarrels with confectioners, laborants, merchants (*Materialisten*), grocers and other groups of artisans and merchants.[58] Laws and privileges were

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[54] See Geyer, 'Hofapotheke,' p. 230.

[55] An inventory of all remedies that were available at the Berlin *Hofapotheke* in 1669 listed 2,303 different kinds of remedies, of which the bulk were presumably natural raw materials (*simlicia*) and Galenic *composita*; see Hörmann, 'Hofapotheke,' p. 216. My estimation concerning the number of chemical remedies is based on the Prussian-Brandenburg pharmacopoeia of 1731, the *Dispensatorium Regium et Electorale Borusso-Brandenburgicum* (Beroloni: Michaelis, 1731), which listed more than 600 different chemical remedies in alphabetical order; among them were large classes of chemical remedies of vegetable origin manufactured in very similar ways, but from different kinds of plants, such as 76 different kinds of *essentia*. On the chemical remedies used in the period from 1670-1750, see also Wolfgang Schneider, *Lexikon zur Arzneimittelgeschichte,* 3, pp. 75-129.

[56] An example of an apothecary's shop with an adjacent *Weinstube* is the Adler-Apotheke in Zehden/Oder; see Grünhagen, *Apotheken in alter und neuer Zeit*, p. 65.

[57] Quoted in Lorenz, 'Ratsapotheke Quedlinburg,' p. 22.

[58] See Manfred Stürzbecher, *Berlins alte Apotheken* (Berlin: Bruno Hessling, 1965), pp. 41-42.

governments' most important means of regulating such controversies. But practice often differed from laws, and apothecaries, too, had to defend their privilege to manufacture remedies against dispensing physicians and the guilds of *Materialisten*, who obtained privileges to produce a restricted number of chemical remedies in several German states.[59]

Eighteenth-century German apothecaries not only sold luxury articles in their officines but also produced goods like confectionery, pigments, tints, soaps, cosmetics and brandy in their laboratories. The Royal *Hofapotheke* in Berlin, for example, supplied the court with perfumes, pomades, hair water, hair powder and the like, even in times of financial hardship.[60] Especially in smaller towns and the provinces, apothecaries could only survive through this additional manufacture and trade. Apart from the distillation of brandy, the making of confectionery was the most widespread sideline of apothecaries in the seventeenth and early eighteenth centuries. We have seen above that the Quedlinburg *Ratsapotheke* had a special *Zuckerkammer* for storing sugar and confectioneries. We also know from the inventories of the Quedlinburg *Ratsapotheke* that it delivered Arabic gum, wax, paper, tints and other office materials as well as varnish, pigments (such as white lead paint, black lead powder, and litharge of silver), and oils to the town magistrate.[61] In Berlin the apothecaries even had the exclusive privilege to sell sugar and confectionery as well as spices, coloured wax and several other materials until 1620.[62] As an impressive number of publications by eighteenth-century German apothecaries dealt with the improvement of manufacture of such products as tints, pigments, brandy, perfumes and pomades, we can assume that the manufacture of these goods was still quite common at that time, despite the fact that governments undertook some efforts to restrict apothecaries' business to the manufacture of remedies.[63]

Summary

Well into the nineteenth century the overlap of the material culture (architecture of laboratories, instruments, vessels, materials, techniques, and scale

[59] See also Beisswanger, 'Arzneimittelversorgung,' on p. 198–230; Ulla Meinecke, *Apothekenbindung und Freiverkäuflichkeit von Arzneimitteln: Darstellung der historischen Entwicklung bis zur Kaiserlichen Verordnung von 1901 unter besonderer Berücksichtigung des Kurfürstentums Brandenburg und des Königreichs Preußen*, (Ph.D. thesis, University of Marburg, 1971).

[60] See Hörmann, 'Hofapotheke,' p. 219.

[61] See Lorenz, 'Ratsapotheke Quedlinburg,' p. 10.

[62] See Hörmann, Hofapotheke, 211. See also Stürzbecher, *Apotheken*, on p. 10, pp. 30-31.

[63] See, for example, related publications in Göttling's *Almanach oder Taschenbuch für Scheidekünstler und Apotheker* (1780-1829).

of instruments) of pharmaceutical art and academic chemistry enabled and stimulated apothecaries to shift their activities from the manufacture of remedies to chemical inquiries into nature. Likewise, it enabled and stimulated academic chemists to explore the possible uses of their insights in the pharmaceutical art. Both, further, might also be drawn into the chemical manufacture of various other goods for which there was a ready market. The same kinds of furnaces, distillation apparatus, crucibles, vessels, solvents and reagents that were used for the manufacture of chemical remedies were also used in the chemical analysis of substances and to explore their chemical properties and ways of chemical transformation. As instruments and materials embody technical possibilities and social habits of labour, the resemblance of eighteenth-century academic chemical laboratories to pharmaceutical laboratories also implied overlapping techniques. Dissolutions, distillations, evaporations, precipitations, calcinations, combustions, smelting and so on were types of operations performed by academic chemists and apothecaries, both for pharmaceutical manufacture and chemical inquiry into nature, be it chemical analysis or chemical experimental history. Not even the scale of instruments and operations in pharmaceutical and academic chemical laboratories differed substantially in the eighteenth century. Like apothecaries, academic chemists used large furnaces and large, immobile retorts of copper, for example, and both used the same types of smaller vessels as well. Pharmaceutical manufacture on the scale of a handicraft corresponded with the scale of chemical experimentation. This latter fact was an additional condition for shifts from manufacture to natural inquiry, and vice versa; it began to change only in the nineteenth century, when, on the one hand, chemists began to introduce smaller analytical instruments and, on the other hand, pharmaceutical laboratories and factories began to produce for a larger market.[64] Moreover, apothecaries' objects of labour, the chemical remedies, and eighteenth-century chemists' predominant objects of inquiry, the chemical substances, also overlapped to a large extent.[65] Most of the chemical substances studied in the laboratories of eighteenth-century academic chemists were also used as chemical remedies. Eighteenth-century chemists constituted substances as multidimensional objects, that is, commodities and scientific objects; and the latter had a perceptible dimension, studied in the experimental histories of substances, as well as an imperceptible dimension, studied in the analysis of chemical composition and in investiga-

[64] On the change in the scale of chemical instruments in academic laboratories see Ernst Homburg, 'The rise of analytical chemistry and its consequences for the development of the German chemical profession (1780–1860),' *Ambix* 46 (1999): 1-31; on the latter change, see the remarks below in the conclusion.

[65] This issue is treated extensively in Klein and Lefèvre, *Materials*.

tions of chemical affinities and chemical reactions. Connoisseurship of a broad range of substances and the ways of their identification, classification and naming was a must for both apothecaries and chemists.

Correspondence does not mean identity. I pointed out above that by no means all eighteenth-century German apothecaries were skilled and knowledgeable chemists, and most apothecaries restricted their interest in chemistry to chemical pharmacy. Furthermore, the manufacture of chemical remedies was only one part of pharmaceutical art in the eighteenth century, when trade with herbal drugs and other *simplicia* as well as the dispensing of Galenic remedies was a significant domain of pharmacy. Inversely, the practice of eighteenth-century German chemists extended to many arts and crafts other than pharmacy, and their theories not only drew conclusions from these multifarious practices, but also hinged on metaphysical traditions, such as the philosophies of principles and of atoms. There were also some (minor) differences between the eighteenth-century pharmaceutical laboratory and the academic chemical laboratory. Whereas the former was primarily a place of manufacture of chemical remedies, the latter was mainly a place of natural inquiry and technological investigation, but only exceptionally a site of manufacture as well.[66] Furthermore, by the end of the eighteenth century academic chemists increasingly implemented precision instruments in their laboratory practice that were not routinely used by apothecaries for purposes of manufacture. Apothecaries had long used balances in the making of remedies, Galenic and chemical, but electrical machines, for example, were not useful for pharmaceutical manufacture. Whereas the pharmaceutical art strongly intersected with academic chemistry, it had only very weak links with areas of experimental philosophy like the study of electricity.

From manufacture to industry

The manufacture of chemical remedies and chemical inquiry into nature strongly overlapped in Germany throughout the eighteenth century. Apothecary-chemists frequently shifted their activities from the production of chemical remedies to the chemical investigation of nature. Inversely, professors of chemistry who spent their entire professional careers at universities, generally were knowledgeable in chemical pharmacy and offered courses on this subject. This mixing of pharmaceutical manufacture and chemical inquiry into nature hinged on a very specific historical constellation: the correspondence between the academic chemical laboratory and the pharmaceutical one; the

[66] It should be noted that in the early eighteenth century academic chemists sometimes also sold their chemical preparations as remedies.

extensive overlap of instruments, vessels, and techniques for pharmaceutical chemical manufacture and for chemical natural inquiry, both with respect to the type and scale of instruments, vessels and techniques; the extensive overlap of commodities and objects of labour (chemical remedies) and academic chemists' most important objects of inquiry, chemical substances; the importance of the apothecary's personal knowledge and connoisseurship of a tremendous range of chemically processed substances and skills that allowed him to perform a variety of different chemical operations; academic chemist's focus on experimental histories and chemical analyses of substances; the hybrid persona of the apothecary-chemist who personally mediated manufacture, technological inquiry and chemical inquiry into nature; the absence of professionalised chemists and the openness of academic institutions to learned practitioners; a broader culture and policy that fostered academicians' useful knowledge and practitioners' expertise, rather than separating application and handiwork from disinterested, pure scientific inquiry. Nowhere else in eighteenth-century Germany did the coupling of learned inquiry into nature and artisanal labour extend so far as in the relationship between academic chemistry and the pharmaceutical art. Nowhere else did such large domains exist of overlapping instruments, techniques, objects of learned inquiry and of labour, connoisseurship of substances and analytical knowledge. Eighteenth-century academic chemistry was also aligned with other arts and crafts, especially metallurgy, dyeing and beaching, and pottery; here, too, sustained interconnections existed, but they were restricted to more specific parts of manufacture, namely, surveys and mapping of resources of materials, control of the manufacturing process and control of the quality of the manufactured products.[67] In the paradigmatic areas of experimental philosophy, such as experimentation with air pumps and electrical machines, the intersection with the arts and crafts was even less extensive, not least because 'philosophical instruments' were first specifically designed for the acquisition of natural knowledge rather than for manufacture.[68]

[67] In metallurgy, the overlapping area concerned assaying, that is the examination of the composition of metal alloys and ores, and the control of smelting processes; in dyeing manufactories, academic chemists controlled the quality of dyestuffs (see Agustí Nieto-Galan, *Colouring textiles: a history of natural dyestuffs in industrial Europe*, (Dordrecht: Kluwer, 2001)); in pottery and the making of porcelain they analysed earths and controlled the quality of pigments.

[68] Here negotiations with instrument makers and the employment of skilled technicians were the most common forms of intersection. It should be noted that in the eighteenth century 'philosophical instruments' such as the electrical machine were quite likely to be found in a wide variety of locations, as Jim Bennett indicates in his essay in this volume. See also Lissa Roberts, 'Science becomes electric: Dutch interactions with the electrical machine during the eighteenth century,' *Isis* 90 (1999): 680-714.

At first glance this history of conjunction of pharmaceutical art and chemistry in eighteenth-century Germany seems to depend entirely on the existence of small-scale pharmaceutical manufacture, personal knowledge rather than an institutional system of scientific transfer and a state of undifferentiated instruments and techniques, applied to both manufacture and natural inquiry, that belonged to a pre-industrial area. Seen from the perspective of modern technoscience and the large pharmaceutical companies of the twentieth and twenty-first centuries, the marked difference of their production apparatus from chemical research instruments, the professionalisation of 'scientists' and the complex network of institutional mediation between science and technology, there seems to be a huge gap between the early form of eighteenth-century technoscience described above and present technoscience. Yet this gap is bridged when some of the early forms of pharmaceutical factories are taken into account. A case in point is the pharmaceutical factory of Heinrich Emanuel Merck (1794–1855), founder of the well-known pharmaceutical concern Merck, who has often been regarded as a leading figure in the process of industrialisation of pharmaceutical art.[69] For this example demonstrates that in addition to the establishment of chemical and pharmaceutical factories that were equipped with new types of machines and production apparatus which differed from research instruments, there was a second way of producing chemical remedies for a non-local market around 1800: the use of existing pharmaceutical laboratories along with the multiplication of existing laboratory apparatus.

H. E. Merck was an apothecary-chemist who began his pharmaceutical apprenticeship in his father's apothecary's shop in Darmstadt after finishing school at the age of sixteen, to proceed shortly afterwards to the chemical-pharmaceutical boarding school of Johann Bartholomäus Trommdorff at Erfurt, where he spent two years.[70] After additional training in apothecary's shops at Eisennach, Frankfurt (Main) and Strasbourg, he studied chemistry, botany, mineralogy and technology at the University of Berlin for one year, returning to Darmstadt in 1816 to take over his father's *Engel Apotheke*. From the mid-1820s on Merck was devoted to the large-scale preparation of the

[69] Vershofen stated that H. E. Merck had 'the greatest thinkable influence on the development of the chemical-pharmaceutical industry;' see Wilhelm Vershofen. *Die Anfänge der Chemisch–Pharmazeutischen Industrie* (Berlin/Stuttgart: Deutscher Betriebswirte-Verlag, 1949, 2 vols.), 1, p. 78f. More recently, Lauterbach designated Merck as a 'pioneer of pharmaceutical–technical technology;' see Irene Lauterbach, *Christian Wilhelm Trommsdorff (1811–1884): Zu Leben und Werk eines pharmazeutischen Unternehmers* (Stuttgart: Wissenschaftliche Verlagsgesellschaft, 2000), p. 73.

[70] For these first chemical-pharmaceutical 'schools' see Klein 'Apothecaries' and the primary and secondary literature quoted there. On Merck's career see Carl Löw, *Heinrich Emanuel Merck* (Darmstadt: E. Roether, 1951).

newly discovered pure alkaline plant substances such as morphine, tannin, narcosine, strychnine, and quinine in the laboratory of his apothecary's shop. He designated his young 'factory', whose pure chemical products were sold in almost all European cities and in New York from the early 1830s on, the 'Chemisches Laboratorium von E. Merck in Darmstadt', a name that is telling as to the nature of this chemical 'factory'.[71] In 1833 he enlarged his apothecary's laboratory for the first time and, three years later, he moved the *Engel Apotheke* into a new, larger building located in the middle of Darmstadt. At least until 1855, when his business had expanded as far as South America and Asia, Merck continued to manufacture remedies in the laboratory belonging to his apothecary's shop. In addition, in 1843 he established a new 'laboratory' outside of the city, and equipped it with new types of machines and apparatus including a mill driven by a steam engine and large steam kettles.

'Large-scale' production had a relative meaning, of course, as Merck produced many of the highly effective, chemically pure alkaline plant substances in ounces rather than pounds.[72] To obtain these pure alkaloids Merck needed huge quantities of raw opium, willow bark, oak-apples and other kinds of roots, seeds and barks, which he ground first by means of a water-driven oil mill located outside of Darmstadt. However, for the subsequent isolation of the alkaloids from the vegetable raw materials, the ordinary chemical vessels and instruments of his apothecary's laboratory were sufficient.[73] As C. Löw pointed out, before the new laboratory was constructed outside of the city in 1843, 'the apparatus, equipment and methods that were common in the apothecary's business sufficed for the production of alkaloids on a large scale; only the mill, driven by the water of the *Darmbach*, had been added after several years as a mechanical aid for grinding the drugs'.[74] But Merck's early achievements also relied on the expansion of his apothecary's laboratory during the 1830s, which enabled him to multiply the number of existing chemical apparatus as well as the number of workmen. In the early 1830s Merck employed up to 23 workmen, and by 1855 their number had increased to 55.[75] As to the

[71] Löw, *Merck*, p. 133. Merck later used the term 'factory' instead of 'laboratory' in the 1850s; see Löw, *Merck*, pp. 132-133.

[72] Löw, *Merck*, pp. 152-158; Gabriele Huhle-Kreutzer, *Die Entwicklung arzneilicher Produktionsstätten aus Apothekenlaboratorien, dargestellt an ausgewählten Beispielen* (Stuttgart: Deutscher Apotheker Verlag, 1989), pp. 133-137.

[73] See, for example, the descriptions in Heinrich Emanuel Merck 'Beitrag zur näheren chemischen Kenntniß mehrerer der vorzüglichsten vegetabilischen Basen,' *Neues Journal der Pharmacie für Ärzte, Apotheker und Chemiker* 20 (1830): 134-164.

[74] Löw, *Merck*, p. 149.

[75] For the number of his employees see Lauterbach, *Leben und Werk* p. 71 and p. 315; Huhle-Kreutzer, *Entwicklung arzneilicher Produktionsstätten*, p. 142.

former point, the multiplication of existing laboratory instruments for pharmaceutical manufacture on a larger scale was not unusual at the time, as we can see, for example, in a report by J. F. A. Göttling on the London Apothecary's Hall and its two large laboratories, where 'all chemical preparations were manufactured in large quantities'.[76] In the London Apothecary's Hall large quantities of 'calx of mercury,' for example, were prepared by using a furnace with a sand bath that had room for 'twenty to twenty-five phials, each of which contained around two pounds of water and was filled half-way with mercury'.[77]

The purchase and processing of huge quantities of drugs, the establishment of a mill for grinding these huge quantities of drugs, the multiplication of existing chemical-pharmaceutical instruments and vessels, the employment of more workmen than in the traditional apothecary's shop, international trade relations, and production for a non-local market: these were the immediate conditions that transformed Merck's traditional apothecary's laboratory into a site of large-scale chemical-pharmaceutical manufacture. The example of Merck shows that, similar to the development of dye industry in the nineteenth century and the smooth replacement of natural dyestuffs by synthetic ones, there was also a continuous transition from small-scale pharmaceutical manufacture to large-scale pharmaceutical industry.[78] Moreover, the sustained interconnection of chemical science and pharmacy existed long before the establishment of large-scale pharmaceutical industry in the late nineteenth century. I have argued above that since the late sixteenth century pharmaceutical art implemented chemical techniques, materials, and knowledge; inversely, the chemistry of that time was both a science and art or 'technology'. The fact that this thoroughly experimental science was established at academies, medical faculties and other scientific institutions as early as the second half of the seventeenth century, that is, long before experimental physics became accepted as an academic discipline, is telling with respect to the emergence and historical development of the experimental sciences and technoscience more broadly. The early acceptance of chemistry as an academic discipline was not least due to academic chemistry's actual utility. Historical studies of the intersection of

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76 Johann Friedrich August Göttling, 'Einige Bemerkungen über Chemie und Pharmacie in England, ' *Almanach oder Taschenbuch für Scheidekünstler und Apotheker*, 1789: 120-144, p 129. On the London Apothecary's Hall, see Anna Simmons, 'Medicines, monopolies and mortars: The chemical laboratory and pharmaceutical trade at the Society of Apothecaries in the eighteenth century, ' Lissa Roberts and Rina Knoef, eds., *The places of chemistry in eighteenth-century Great Britain and the Netherlands* (special issue of *Ambix* (2006)): 221-236.

77 Göttling, 'Einige Bemerkungen, ' p. 131.

78 On the transition of the manufacture of natural dyestuffs to synthetic dye industry see Nieto-Galan, *Colouring Textiles*.

chemical science, technology and governmental patronage prior to the late nineteenth century, when technoscience became a more visible institution, reveal that academic experimentation developed not only as a new method within natural philosophy but also as a technoscientific practice that had a life of its own.

Primary sources

Anonymous, 'Fragmente aus dem Tagebuche eines Apothekers, ' *Journal der Pharmacie* 1 (1793): 40–47.

Archiv der Berlin-Brandenburgischen Akademie der Wissenschaften (ABBAW), Bestand Preußische Akademie der Wissenschaften (1700–1811).

Crell, Lorenz 'Lebensgeschichte Andreas Sigismund Marggraf's, Directors der physikalischen Klasse der Königl. Preuß. Akademie, Mitglieds der K. Akademie der Wissenschaften zu Paris und der Churfürstl. Maynzischen zu Erfurt,' *Chemische Annalen für die Freunde der Naturlehre, Arzneygelahrtheit, Haushaltungskunst und Manufacturen* 1 (1786): 181–192.

Diderot, Denis J. and Jean LeRond d'Alembert, *Encyclopédie ou dictionnaire raisonné des sciences, des arts, et des métiers* (Stuttgart: Frommann, 1965, 35 vols.; first published 1751–1780), vol. 24.

Dispensatorium Regium et Electorale Borusso-Brandenburgicum (Beroloni: Michaelis, 1731).

Göttling, Johann Friedrich August, 'Einige Bemerkungen über Chemie und Pharmacie in England, *Almanach oder Taschenbuch für Scheidekünstler und Apotheker* (1789): 120–144.

Liphardt, Johann Christian Lüderitz, 'Bemerkungen, Wünsche und Vorschläge für sämtliche Herren der Apothekerkunst; als ein Nachtrag zur moralischen Disziplin des Herrn Bindheim,' *Almanach oder Taschenbuch für Scheidekünstler und Apotheker* (1784): 70–98.

Marggraf, Andreas Sigismund, *Chymische Schriften*, (Berlin: Arnold Wever, 1761–67, 2 vols.).

Merck, Heinrich Emanuel, 'Beitrag zur näheren chemischen Kenntniß mehrerer der vorzüglichsten vegetabilischen Basen', *Neues Journal der Pharmacie für Ärzte, apotheker und Chemiker*, 20 (1830): 134–164.

Neumann, Caspar, 'Kurtze Nachricht von der Oeconomie und Verwaltung der Koenigl. Preuss. Hoff-Apotheken,' Alfred Exner, ed., *Der Hofapotheker Caspar Neumann (1683–1737)*, (Berlin: Triltsch & Huther, 1938), pp. 71–81.

Nicolai, Friedrich, *Beschreibung der Königlichen Residenzstädte Berlin und Potsdam aller daselbst befindlicher Merkwürdigkeiten und der umliegenden Umgebung* (Berlin: Nicolai, 1786, 3 vols.).

Queitsch, Anton Philipp 'Memoria Neumanniana,' in Alfred Exner, *Der Hofapotheker Caspar Neumann (1683–1737)*, (Berlin: Triltsch & Huther, 1938), pp. 7–15.

'The charter'd Thames 1791-1804'. Adapted from Robert Rowe, 'Map of London exhibiting the various improvements,' published May 1804.

‘The charter’d Thames’: naval architecture and experimental spaces in Georgian Britain

Simon Schaffer

To see the various and multiform pieces of timber that compose a Ship’s frame, taken from their scattered situation in the dock-yard and placed in their proper order so as to throw on the sight, the form of a 100 gun Ship &c. and with such exactness as not to require one quarter of an inch to be taken off with the adze, this to a mind capable of reflection is at once an argument for the Immortal Reason of Man, and a strong plea for the encouragement of those ingenious Artists.

William Shrubsole, *A plea in favour of the shipwrights belonging to the Royal Dock Yards* (1770)

Although theory alone may not be adequate to the solution of these difficulties, yet when combined with experiments and observations, it may be probably employed with great advantage in these researches…Since naval architecture is reckoned among the practical branches of science, every voyage may be considered an experiment, or rather as a series of experiments, from which useful truths are to be inferred towards perfecting the art of constructing vessels: but inferences of this kind cannot well be obtained except by acquiring a perfect knowledge of all the proportions and dimensions of each part of the ship; and secondly by making and recording sufficiently numerous observations on the qualities of the vessel, in all the varieties of situation to which a ship is usually liable in the practice of navigation.

George Atwood, *Geometrical Propositions determining the Stability of Ships* (1796)[1]

Terms such as ‘reason’, ‘theory’ and ‘experiment’ were highly charged words in eighteenth-century Britain. Rather than using them as self-evidently explanatory expressions, they should be put back in the places where politicised languages of art and practice provided their peculiarly forceful sense. The former of these epigraphs comes from a polemical pamphlet by a master mast-maker and Methodist lay preacher, William Shrubsole, who campaigned against wage cuts in the major naval dockyards. Shrubsole considered dockyard workers’

[1] William Shrubsole, *A plea in favour of the shipwrights belonging to the Royal Dock Yards* (Rochester: Fisher, 1770), pp. 9-10; George Atwood, ‘The construction and analysis of geometrical propositions assumed by homogeneal bodies which float freely, and at rest, on a Fluid’s surface: also determining the Stability of Ships and of other floating bodies,’ *Philosophical transactions* 86 (1796): 46-130, p. 130.

ingenious, rational and collective exactitude a profound moral resource in the fight against the expropriation of their skill. The latter epigraph is from a paper delivered by a Cambridge mathematics lecturer and government administrator, George Atwood, to the Royal Society as part of a series of geometrical analyses of ship stability and friction. Atwood and his allies sought to bring the behaviour of naval vessels within the scope of an ambitious programme of dockyard management and experimental trials promoted by a genteel Society for the Improvement of Naval Architecture. The dockyard preacher and the varsity sinecurist drew maps that quite differently configured the form, place and power of knowledge vested in naval shipbuilding. This essay suggests that such rival maps were crucial in contests about the conduct and status of naval shipbuilding and the more general politics of labour. Terms such as theory and experiment helped these maps assign explicit knowledge and traditional craft to different sites, whether wood sheds and dockyard lofts, city counting houses and drawing offices, or lecture-rooms and academies.

Consider the vocabulary surrounding the short-lived School of Naval Architecture set up at Portsmouth Naval Yard in 1811. This school was part of a government campaign to overhaul apprenticeship by recruiting select boys to train as naval dockyard officers quite segregated from other workmen. Trainees spent each morning studying mathematical analysis and scientific theory, including Atwood's geometrical essays.[2] In the pages of London's leading journal of applied sciences, the School's supporters condemned received dockyard learning as 'derived from imperfect experience' rather than 'the principles and maxims of theory'. Ultimately, they opined,

> …the cultivators of this noble art will have the gratification of finding it no longer the sport of accident and chance, but guided by principles and rules, true and unexceptionable in their nature, and unfailing in their application, the light of a pure geometry guiding their steps in all their investigations.

The contrast between accidents of practical experience and the universal scope of noble theory was clearly drawn. But self-styled 'working shipwrights' rejected this chart in the radical London press, mocking the legitimacy of 'principles lawfully begotten in the cranium of lawfully appointed professors of abstractions.' Some of the greatest mathematicians, they averred, were also totally bereft of any practical knowledge or business sense. 'The calculus will not make them good shipbuilders'.[3]

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[2] Roger Morris, *The royal dockyards during the Revolutionary and Napoleonic Wars* (Leicester: Leicester University Press, 1983), pp. 113-14.

[3] 'Observations on naval architecture and on the state of science in our dock-yards,' *Quarterly journal of science, literature and the arts* 18 (1825): 320-22; 'Naval architecture,' *The chemist* 2 (1825): 349-51,

These were pointed words in later Georgian political debates. Whose skills would prevail to fashion an order of either hierarchic deference or progressive liberty? Educational reform programmes and challenges to conservative elites gave weight to conflicts about the distribution of mental and manual skill across the social map. Specific to these rival charts of shipwrights' intelligence was the vitality of institutional traditions of naval architecture and their central role in the activities of a militant and powerful maritime state. The development and revision of these projects is the focus of what follows.

The naval dockyards of Georgian Britain were sites of sophisticated skill and tool use, a highly-developed division of task labour and form of production where enterprises of state, commerce and war were all put to work. The crafts of woodworking and smithing, cordage and drafting, were set up in complex systems of discipline, collaboration and competition there. The Royal Navy was the nation's largest technical enterprise and the centre of the fiscal-military state. These dockyards thus provide a remarkable site for historical reflection on the relation between knowledge and skill in the epoch of industrialisation.[4]

The yards' significance was long apparent to contemporaries. At Sheerness on the Kent coast in the early eighteenth century Daniel Defoe compared the naval yards to a 'well-ordered city' where 'every man knows his own business' and co-operative production was the order of the day.[5] A large warship could require two thousand oak trees, each of which needed careful judgement and handling, 'conversion' in local jargon, by intricately co-ordinated groups of skilled labourers. Remaining wood was turned into 'chips', the customary compensation that the workforce took away for private use. A mid-eighteenth century guide to the London trades explained that 'the principles of this art are much more complicated and the execution infinitely more difficult' than any other form of architecture. Naval carpenters 'must learn the theory as well as the practice' and 'be masters of designing, figures and mensuration. Defoe spotted the importance of 'moulds', the moveable templates from which wood

428-30. For the politics of the Royal Institution's *Quarterly journal*, see Morris Berman, *Social change and scientific organization: the Royal Institution 1799-1844* (London: Heinemann, 1978), pp. 141-5; for the politics of Thomas Hodgskin's radical organ *The chemist*, see Iwan Morus, *Frankenstein's children: electricity, exhibition and experiment in early nineteenth century London* (Princeton: Princeton University Press, 1998), pp. 113-14 and Jan Golinski, *Science as public culture: chemistry and enlightenment in Britain 1760-1820* (Cambridge: Cambridge University Press, 1992), pp. 243-44.

4 John Brewer, *The sinews of power: war, money and the English state 1688-1783* (London: Unwin, Hyman, 1989), pp. 34-37; Nicholas Rodger, *The command of the ocean: a naval history of Britain 1649-1815* (London: Penguin, 2005), pp. 292-3.

5 Daniel Defoe, *A tour through the whole island of Great Britain*, Pat Rogers ed. (1724; Harmondsworth: Penguin, 1971), p. 125.

was judged, cut and shaped into the skeleton of the ship. Just so, the trade guide emphasised that these moulds set out the ship's 'true dimensions every way, and from thence, by scale and compass, is measured every timber-plank and beam that is laid in her from going into the stocks till she is launched'.[6]

Co-ordination and moulding mattered because naval dockyards were vast enterprises. Portsmouth yard and Deptford doubled in size during the eighteenth century, while Plymouth expanded almost six-fold. The yards nearer London gained increasingly specific functions. Warships were repaired and cleaned round Sheerness, while Woolwich and Chatham focused more on shipbuilding. Deptford's naval yard acted as the principal store depot, worked in close proximity to the private yards round Rotherhithe. This complex system came under the ultimate management of the large and unwieldy Navy Board, based in the earlier eighteenth century just west of the Tower of London.[7] Defoe and his ilk represented the yards as akin to production utopias on a metropolitan scale, where the invisible hand of reason ruled an amicable choreography of labour in 'well-ordered cities'. The naval arsenals and yards were large-scale laboratories where novel layouts were tried out. Within the yards, spaces were differentiated by the activity discharged there, organised in grids and turned into sites of intense technical application. The power relations of the dockyards relied on a mixture of military rank and capital investment.[8]

But utopia's place on the map is nowhere. Naval shipwrights and their civilian counterparts were extremely resistant to the imposition of discipline from without. The shipyard's moral economy existed to protect property in artisan skill and wage rates. The very term 'strike' became widely used in 1768 when shipwrights paralysed the London fleet by striking its sails. The Thames Yards maintained a traditional rhythm, refitting the East India Company fleets in the autumn and building new ships in the spring. Sudden mobilisation and re-equipment could easily disrupt this economy.[9] So could changes in power between private contractors and the major royal yards. War years often saw a growth in labour militancy in yards whose military and economic value had

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6 R. Campbell, *The London tradesman* (London: T. Gardner, 1747), pp. 298-99.

7 N. A. M. Rodger, *The wooden world: an anatomy of the Georgian navy* (London: Fontana, 1988), pp. 33-36; Jonathan Coad, *The royal dockyards 1690-1850* (Aldershot: Scholar Press, 1989), p. 3; Peter Linebaugh, *The London hanged: crime and civil society in the eighteenth century* (London: Penguin, 1993), pp. 373, 382-3.

8 Bruno Fortier and Alain Demangeon, *Les vaisseaux et les villes* (Liège: Mardaga, 1978), pp. 30-32 and Thomas Markus, *Buildings and power: freedom and control in the origin of modern building types* (London: Routledge, 1993), pp. 257-61 discuss naval yards as laboratories and visionary cities.

9 Roger Morriss, *The royal dockyards during the Revolutionary and Napoleonic Wars* (Leicester: Leicester University Press, 1983), pp. 28-29, 60-61; Marcus Rediker, *Between the devil and the deep blue sea: merchant seamen, pirates and the Anglo-American maritime world 1700-1750* (Cambridge: Cambridge University Press, 1987), p. 110.

correspondingly increased.[10] What might seem to some managers as rational reforms, were resisted by militant shipwrights as infringements on their moral rights and traditions.[11]

The naval yards therefore provided challenges and opportunities for both their workforce and observers to chart and reorder embodied labour in the name of better commanding the work process. A geography of skill in these milieux was at once a programme for management and site of frequent conflict. The polemics around dockyard layout help show why expressions such as 'theory' or 'reason' cannot easily be used to explain the process of shipbuilding and its appropriation, whether by mathematical practitioners, naval administrators or artisan activists. Far from self-evident, these notions were, rather, produced and defined in the act of representing the processes of production and conflict developed around the yards. This essay discusses exemplary projects in eighteenth-century British naval architecture that used real and imaginary geographies of dockyard skill to map hierarchies and establish the rights of producers and masters. In particular, the aim is to understand how some projects counted as experiments designed to try out the power of mathematical analysis and managerial control. Special places had to be reorganised so that work done in the yards would count as representative of the characteristic behaviour of ships. Following Ken Alder's account of the theory and practice of gunnery and ballistics in the French Enlightenment, this essay argues that controversial changes in the form of life of engineers and artisans accompanied programmes to transform and manage the role of analysis and experiment.[12]

These projects occurred in an historical context that helps make sense of the complex relationship between analytical and labour management. Before discussing the naval yards of eighteenth-century England, we need to return to the seventeenth-century Venice Arsenal. Here we confront key moments in the history of rational mechanics and state-sponsored craft enterprise, both crucial to the early modern military system of statecraft. Gunnery and naval architecture matter to historians of science, too, not least because they exemplify the relation between mathematical analysis and practical application in

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[10] Peter Linebaugh and Marcus Rediker, *The many-headed hydra: sailors, slaves, commoners and the hidden history of the revolutionary Atlantic* (Boston: Beacon Press, 2000); Kenneth Lunn and Ann Day, eds., *History of work and labour relations in the Royal Dockyards* (London: Mansell, 1999).

[11] Rodger, *Command of the ocean*, pp. 298-99; Linebaugh, *London hanged*, p. 384; Roger Morriss, 'Samuel Bentham and the management of the Royal Dockyards,' *Bulletin of the institute of Historical Research*, 1981, 54: 226-40; William J. Ashworth, 'System of terror: Samuel Bentham, accountability and dockyard reform during the Napoleonic wars,' *Social history*, 23 (1998): 63-79, on pp. 73-76.

[12] Ken Alder, *Engineering the Revolution: arms and enlightenment in France 1763-1815* (Princeton: Princeton UP, 1997), pp. 89-98.

Galileo's *Two new sciences* (1638). In search of socio-technical sources for the application of abstract mathematical modelling, mid-twentieth century social scientists such as Edgar Zilsel and Franz Borkenau looked to the Venice Arsenal as a site where scholarship and craft met. 'All his life', Zilsel wrote, 'Galileo liked to visit dockyards and talk with the workmen.' The historian Alexandre Koyré retorted that 'Galileo did not learn *his* business from the people who toiled in the arsenals and shipyards of Venice. Quite the contrary: he taught them *theirs*'.[13]

Few historians of science accepted the plausibility of materialist analyses. A. R. Hall insisted that seventeenth-century inquirers 'were led to discoveries in mechanics less by their practical usefulness than by the logic of historical development'. Eduard Dijksterhuis dismissed Borkenau's work as 'altogether unfounded'. He was, however, sufficiently impressed by Zilsel's writing to concede that artisans' work at least provided mathematical mechanics with its subject matter. But the fit between the two seemed so inevitable that it barely required historical analysis. According to Dijksterhuis, reliable knowledge emerged '*naturally* from the pursuit of technical trades,' while mathematical mechanics 'came into its own *spontaneously*' in these enterprises.[14] Rather than appeal to natural spontaneity or the iron logic of theoretical development, the emphasis here is on engineered mediations and hierarchies. As Mary Henninger-Voss points out in her essay for this book, it behoves historians to concentrate on the cunning mediations between the different spaces of expertise and knowledge in early modern Europe, between offices, classrooms, studios, libraries and workshops.

One important version of the puzzle of mediation between the spaces of naval architecture was the scale problem. The problem was already adumbrated in Vitruvius' celebrated *Ten Books on Architecture*. The Roman author explained how some machines could be enlarged from small models, some were to be built independently of any model and some 'which appear feasible in models… when they have begun to increase in size are impracticable'. The Vitruvian context was military; so was that of Galileo's analysis. His *Two new sciences* opens with a patrician dialogue set in the Venice Arsenal that explicitly reflects on whether smaller models could be used accurately to describe the behaviour

[13] Franz Borkenau, 'Zur Soziologie des mechanistischen Weltbildes,' *Zeitschrift für Sozialforschung* (1932), 1: 311-35, p. 312, translated in *Science in context* 1 (1987): 109-27; Edgar Zilsel, 'The sociological roots of science,' *American journal of sociology* 47 (1942): 544-62, pp. 555-56; Alexandre Koyré, 'Galileo and Plato,' *Journal of the history of ideas* 4 (1943): 400-28, p. 401n. 6; See also Alfred Sohn-Rethel, *Intellectual and manual labour: a critique of epistemology* (London: Macmillan, 1978), p. 124.

[14] A. R. Hall, *Ballistics in the seventeenth century* (Cambridge: Cambridge University Press, 1952), pp. 160-2. E. J. Dijksterhuis, *The mechanization of the world picture* (Princeton: Princeton University Press, 1986), pp. 241-3. The stresses are mine.

of large-scale ships. Galileo reported dockyard artisans' view that they could not. His patrician interlocutors sneer at this opinion, since scale-insensitive geometry was supposed to work universally. Though the Arsenal master artisans lacked the analysis to demonstrate this truth about scaling, Galileo rejoined, they were right and the patricians wrong. He further proclaimed that these passages on structural stability launched an entirely new science. They also connected the status of artisans' local knowledge and technique with that of small-scale constructed representations. 'Here you may notice how conclusions that are true may seem improbable at first glance, yet when only some small thing is pointed out, they cast off their concealing cloaks and, naked and simple, gladly show off their secrets'.[15]

The language of sudden reversal of force neatly applied Galileo's Archimedean mechanics to the programme of practical and mathematical knowledge. Despite the doubts of many previous historians, it is now clear that the places of early modern naval enterprise did matter to this programme. Arsenal shipwrights drew plans to establish ship dimensions, while workers and managers debated the puzzles of projection from such models. In the Arsenal, the mould lofts and timber conversion characteristic of much later naval production were already well developed as problems both of managerial discipline and sophisticated ship design.[16]

Galileo, who recruited his chief instrument maker from among the Arsenal's metalworkers, had quite direct experience of these enterprises. Venetian military authorities held inquiries into ways of enlarging galleys to carry more and heavier guns and asked Galileo for advice. In the event, his counsel was dismissed in favour of that of the chief Arsenal artisans, experts on the challenges of scaling up warship design. Practical management of the naval dockyards thus provided an immediate context for the scale problems that open the *Two new sciences.* These kinds of rational mechanics depended explicitly on the mediations between carriers of mathematical, administrative and practical knowledge.[17]

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[15] Vitruvius, *Ten books on architecture*, ed. Morris Hicky Morgan (Cambridge, MA.: Harvard University Press, 1914), p.316 (book 10, chapter 16, para.5); Galileo Galilei, *Two new sciences*, ed. Stillman Drake (Madison: University of Wisconsin Press, 1974), p. 14.

[16] Frederic Chapin Lane, *Venetian ships and shipbuilders of the Renaissance* (Baltimore: Johns Hopkins UP, 1934), pp. 95-96 (for geometry and models); Robert C. Davis, *Shipbuilders of the Venetian arsenal* (Baltimore: Johns Hopkins University Press, 1991), pp. 120 (for chips) and 178-9 (for worker-management relations).

[17] Jurgen Renn and Matteo Valleriani, 'Galileo and the challenge of the Arsenal,' *Nuncius* 16 (2001): 481-503. Compare Hélène Vérin, *La gloire des ingénieurs: l'intelligence technique du 16e au 18e siècle* (Paris: Albin Michel, 1993), pp. 314-17. For Galileo's instrument manufacture and the Arsenal see Silvio Bedini, 'Galileo and scientific instruments,' in Ernan McMullin, ed., *Galileo man of science* (New York: Basic Books, 1967), 127-54 on p. 132.

Galileo's formulations of the scale problem were distributed in Britain through comparable networks of practical mathematical enterprise. A number of texts in ballistics, composed by Civil War veterans and ambitious mathematical practitioners, frequently cited him. The London weaver Robert Anderson's *Genuine use and effects of the gunne* (1674) prompted ballistic trials at the Tower of London and debates with academics such as John Wallis, James Gregory and Isaac Newton. Various accounts of *Two new sciences* were available in Restoration London, not only through the Royal Society but also through works closer to metropolitan mathematical practitioners. A section of Thomas Salusbury's *Mathematical collections*, issued in 1665, offered a translation of Galileo's text, while others carried discussions of hydraulic oeconomy, the recovery of sunken ships and the puzzles of floating bodies.[18] Crucial was the publication in 1730 of an English version of *Two new sciences* by the Greenwich astronomer Thomas Weston since prior examples had become scarce. The naval context of his project is telling. Weston worked from early 1699 as assistant to the Astronomer Royal, John Flamsteed, who praised him as a heaven-sent draughtsman and calculator. Colleagues reckoned he was Flamsteed's 'principal instrument,' as he aided negotiations between Newton and the Astronomer Royal and furthered work on the Greenwich star catalogues. Like his fellow assistant James Hodgson, who also taught naval mathematics, Weston set up as mathematics teacher after leaving Flamsteed's service in 1706. From 1712 he trained boys from the nearby Royal Naval Hospital in calculation and kindred disciplines as preparation for naval careers. Weston died in 1728 with his Galileo edition almost complete. His brother took over the Greenwich school and saw the book through the press. The preface contrasted the 'eternal subject' of local motion with the more useful and practical puzzles of resistance, cohesion and scaling. This helped make such problems the concerns of several eighteenth century mathematical practitioners.[19]

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[18] Robert Anderson, *Genuine use and effects of the gunne* (London: Berry and Morden, 1674), pp. 26-27; compare Thomas Venn, *Military and maritime discipline* (London: Pawlett, 1672) and Stillman Drake, 'Galileo in English literature of the seventeenth century,' in McMullin, ed., *Galileo man of science*, 413-31 on p. 426. Nick Wilding is at work on a thorough account of Salusbury's texts.

[19] For Weston and Flamsteed see Francis Baily, *An account of the Reverend John Flamsteed* (London: Admiralty, 1835), p. 64; Eric Forbes, Lesley Murdin and Frances Willmoth, eds., *Correspondence of John Flamsteed*, 3 vols. (Bristol: Institute of Physics, 1995-2001), vol. 3, p. 105 (Sharp to Flamsteed, 25 November 1704). For Hodgson's teaching see Robert Iliffe, 'Mathematical characters: Flamsteed and Christ's Hospital Royal Mathematical School,' in Frances Willmoth, ed., *Flamsteed's Stars* (Woodbridge: Boydell and Brewer, 1997), pp. 115-44. For Weston's teaching see Kim Sloan, 'Thomas Weston and the Academy at Greenwich,' *Transactions of the Greenwich and Lewisham Antiquarian Society* 9 (1984): 313-33, on pp. 318-23. The preface is in Galileo, *Mathematical discourses concerning two new sciences* (London: Hooke, 1730), pp. ix-xi.

The pedagogic enterprises of mathematical practitioners such as Hodgson and Weston helped construct a world containing rational mechanics texts, instrument shops, stationers and naval trainees both in Greenwich and around the Navy Board and the Tower. This was where a form of practical mathematics was cultivated, ambitious to connect Galileo and Newton's principles with the demands of navigation, shipbuilding and commercial engineering.[20] The development of such connections was never straightforward. Rather, coffee-house and market entrepreneurs wrestled with the practical links between models and paper schemes and the complex structures of mines, bridges and dockyards. They claimed their expertise included just the skill needed to weld these settings together. It might be hard to apply rational principles in these workplaces, they argued, but specialists could do it.

Alongside Galilean reflections on how to derive lessons for ships from structural scale models, Newton's mathematical mechanics offered these men comparable resources and frustrations. In the second book of *Principia mathematica* (1687), Newton set out the mechanical theory of fluid resistance that dominated academic theories of ship motion for a century. His doctrine implied that fluid resistance varied as the square of the moving body's velocity, its maximum cross-sectional area, and some constant dependent on the shape of the vessel. For a sphere, this constant was one-half. The analytic project was thus to search for the solid of least resistance, a task well beyond and often inimical to the everyday work of shipwrights.

Newton maintained his interest in naval training as advisor to the Royal Mathematical School where Hodgson and his colleagues taught mathematics and navigation as preparation for apprenticeship at sea. The issue of the local character of artisan knowledge and the allegedly general powers of rational mechanics emerged once again in this context. Newton told the Mathematical School's treasurer in 1694 that

> …a Vulgar mechanick can practice what he has been taught or seen done, but if he is in error he knows not how to find it out and correct it, and if you put him out of his road, he is at a stand; whereas he that is able to reason nimbly and judiciously about figure, force and motion is never at rest till he gets over every rub.[21]

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[20] Larry Stewart, *The rise of public science: rhetoric, technology and natural philosophy in Newtonian Britain 1660-1750* (Cambridge: Cambridge University Press, 1992), pp. 114-15 (for Hodgson) and 133-41 (for Weston and public lectures).

[21] Isaac Newton, *Principia mathematica, the third edition with variant readings*, ed. Alexandre Koyré and I. Bernard Cohen (Cambridge: Cambridge University Press, 1972), p.463 and Isaac Newton, *The Principia*, translated by I. Bernard Cohen and Anne Whitman (Cambridge: Cambridge University Press, 1999), p.183; Newton to Paget, 1694, in *Correspondence of Isaac Newton*, ed. H.W. Turnbull, J. F. Scott and A. R. Hall (Cambridge: Cambridge University Press, 1959-77), 7 vols., vol. 3, pp. 359-60;

Just as Venetian dockyards were important settings for Galileo's experiences of reasoning from model schemes to real ships, the London yards provided challenges for Newton's doctrine of the solid of least resistance and its tests. In 1733, the Navy Board's chief surveyor Jacob Acworth proposed new warship hull designs based on 'the principle of the solid or curve of least resistance in cleaving the water as propounded by Mr Newton'. At Deptford naval yard, master shipwrights built a series of wooden models of this ideal shape and 'determined the new manner of building from that shape which moved through the water with most ease'. A French naval architect and spy, Blaise Olivier, was sceptical about these trials and their results, noting a puzzle that would haunt naval architecture throughout the eighteenth century. Exaggerating one design feature, such as minimising hull resistance, damaged ship performance in other respects, such as stability when carrying heavy guns. Olivier and his colleagues understood that the geometry of rational mechanics often assumed, then dictated easily tractable curves. Even if 'irregular curves offer a greater resistance,' he remarked, 'it is not true that they should never be employed in the building of ships, where they are unavoidably necessary in the waterlines close to the keels'.[22] These puzzles connected geometry with politics. The fundamental problem, as practitioners knew, was that the application of exact trials and mathematical analysis to 'regular curves' and rational models demanded managerial surveillance of the way timber was cut, shaped and fitted in the work of conversion and moulding. This required firm and sometimes violent challenges to the local practices of the mould lofts and dockyards. In order to make the naval yards production utopias fit for the conduct of experimental design, where hulls of minimal resistance could be tried or manufactured, it was necessary to overcome the regimes of artisan co-ordination cultivated there. Terms such as 'theory' and 'art' acquired their polemical sense as part of this struggle.

Ample testimony to the nature of these challenges was presented in the influential work of the Wearside mathematical writer and teacher William Emerson. Emerson criticised metropolitan systems of patronage and inquiry and advocated applying Galilean and Newtonian mechanical principles to the problems of navigation and naval architecture. He built his own model ships and cultivated a large readership of interested mechanics and artisans. In his principal mechanics textbook, Emerson copied the scale problem as presented in Weston's 1730 edition of Galileo. He then applied these arguments about

A. R. Hall, 'Architectura navalis,' *Transactions of the Newcomen Society* 51 (1979-80): 157-73, p. 164; Iliffe, 'Mathematical characters'.

[22] Rodger, *Command of the ocean* (cit. n. 4), p. 413; David H. Roberts, ed., *Eighteenth century shipbuilding: remarks on the navies of the English and Dutch by Blaise Olivier* (Rotherfield: Boudriot, 1992), pp. 181-4.

inference from small models to large structures to what he called 'the noblest machine that ever was invented,' the ship.[23] During the naval wars of the 1750s, Emerson worked out ways of aiding carpenters to build hulls to minimise resistance. He soon discovered how hard it was to realise these projects, though built 'upon principles … as certain and demonstrative as the Elements of Euclid'. His only recourse was to lambast naval resistance to his models of fluid resistance in print.[24]

Such polemics set the tone for rival accounts of hull design, fluid resistance and experimental trials in the later eighteenth-century yards. Several practitioners, such as the Liverpool pilot and harbour master William Hutchinson, conducted complex experiments on ship stability and hull design using small-scale models to test textbook theory. But performing these trials alone could not compel assent in the naval system.[25] It is thus salutary to reflect on the highly contested relation between labour decomposition and analytical planning in the Georgian dockyards. William Shrubsole's text provides a good case. Soon after Defoe's visit there, Shrubsole joined the Sheerness naval dockyard as apprentice shipwright, then in the 1750s became an evangelical preacher along the Kent coast. Ultimately made master mast-maker at the Sheerness and Woolwich dockyards, he defended fellow shipwrights' claims to skill and status. His text was an explicit and revealing part of a campaign for overtime and better pay, featuring familiar tropes of the artisans' sense of their place on the map of ingenuity and expertise.[26] Shrubsole noted recent and dramatic improvement in shipwright's 'most complex and intricate art. ' According to him, the process of efficient 'conversion' now possessed 'a certain oeconomy,' characterised by 'the utmost precision which is a prodigious saving to the government.' Further, what had once been 'secrets formerly locked up in a few ingenious breasts, are now shared in common'.[27]

In his map of shipwrights' new precision and skill, Shrubsole designated the right place of 'theory' and 'practice'. Artisans deserved better because they had made the theoretical innovations that generated these savings and

[23] William Emerson, *Principles of mechanics* (London: Innys and Richardson, 1754), pp. 136-40, directly paraphrases Galileo, *Mathematical discourses*, pp. 4-6. Ship design is discussed in Emerson, *ibid.*, p. 286 and the solid of least resistance applied to naval architecture in *Principles of mechanics*, 2nd ed. (London: Innys and Richardson, 1758), pp. 236-8.

[24] William Emerson, *Mechanics or the doctrine of motion* (London: Nourse, 1769), pp. iii-iv.

[25] William Hutchinson, *Treatise on practical seamanship* (Liverpool: for the author, 1777), pp. 30-31. Compare Basil Harley, 'The Society of Arts' model ship trials 1758-1763,' *Transactions of the Newcomen Society* 63 (1991): 53-71.

[26] J. M. Haas, *A management odyssey: the royal dockyards 1714-1914* (Lanham: University Press of America, 1994), p. 34.

[27] Shrubsole, *A plea*, pp. 9-11.

sharings. 'This has not been done,' he expostulated, 'by great Mathematicians communicating certain data to the Shipwrights, and thus robbing them of the merit of the discovery; it has been accomplished by themselves, men who served their apprenticeship in the yards…they have founded this ingenious and useful Art upon the indisputable principles of Mathematic truth and confirmed them by practice'. Shrubsole aimed here to move the rights of recompense back to the shipwrights. He embodied the shift in a telling analogy: 'the Shipwrights may be termed the Primum Mobile of our system with far more truth than this term was anciently used by the Astronomers. They set the great wheels of commerce and war in motion'.[28]

Shrubsole's cosmology was designed to set calculation and mathematical ingenuity firmly in the workshops of the naval dockyards. His sermon thus contested two closely related projects in eighteenth-century naval policy: a managerial programme to break down the labour process of ship construction into components subject to economic scrutiny and the cash nexus; and an erudite programme to break down the design and behaviour of warships into manageable puzzles for mathematical inquiry. The relation between these two programmes was a major concern both for naval administrators and for mathematical practitioners. It thence became the stuff of newfangled political economy.

In his essay in the following section of this volume, Adrian Johns rightly emphasises that Charles Babbage defined his age by identifying industrial systems of mechanised uniformity. Babbage found significant resources for his standardised machinofacture in the naval dockyards. His early ambitions to calculate and print navigation tables automatically for the Navy depended on the labour of machine-tool workshops, whose masters were closely linked with dockyard reform. Between 1796 and 1807 the entire labour system at Portsmouth dockyard was overhauled. The scheme's leader was Samuel Bentham, former shipwright at Woolwich and Chatham in the 1770s, hired as Inspector of Naval Works. Bentham started with an experimental shipyard near Southampton to try standardised and automated shipbuilding. In collaboration with the engineers Marc Brunel and Henry Maudsley, he hired specialist chemists and mechanists, replaced wooden tools with steam-driven all-metal machinery and sought to embody separate artisan tasks in purpose-built lathes and clamps. One key task was the production of pulley blocks, which minimised friction on board ship. Once he'd completed block-machines for Portsmouth, Maudsley made a similar set for the Chatham naval yard.

[28] *Ibid.*, pp. 8-9, 15.

Babbage learnt much from this manufacture, whose aim was a general system of surveillance, control and analytical decomposition subject to the widest possible public scrutiny. Compensation through wood chips would be transformed into a rigid system of cash payments. The scheme involved more than mechanising block production. It incorporated a radical overhaul of apprenticeship, a new accountancy system for wage-rates and store costs, and the deliberate introduction of formal 'theory' into training.[29]

In all these projects, promoters of naval yard labour reform sought to make terms such as 'theory' and 'science' theirs.[30] Equally important was their drive to regulate the yards' spatial order and the circulation of paper. Their visions of 'a consistent and well-digested system' explicitly emphasised how the labour process's decomposition through paper work and managerial control had to accompany its technical reorganisation in dockyards and throughout the British economy. Significantly, when offering his readers an account of how to move from 'making' to 'manufacture', Babbage chose the example of Maudsley's engineering work for the Navy Board.[31]

This political economy taught that division of labour in the workshops, increased mechanisation and marked increases of scale combined to provide settings where deliberate deployment of analytic sciences, such as mathematics and chemistry, might become both feasible for analytical mathematicians and profitable for administrative capital.[32] The theme was common in later eighteenth century manifestos of naval reform, which contrasted the 'dull and ignorant prejudice' of early eighteenth-century British naval builders with the promises of modern management. Against such views, militant shipwrights contested both the executive decomposition of their skilled labour into measured elements and the prerogative of analytical mathematicians over ship design and movement.[33]

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[29] Bentham's programme is described in Linebaugh, *London hanged*, pp. 396-401; Morriss, 'Samuel Bentham'; Ashworth, 'System of terror', pp. 65-76. The machinery is described in Carolyn Cooper, 'The Portsmouth system of manufacture,' *Technology and culture* 25 (1984): 182-225. Babbage's dependence on this programme is discussed in Simon Schaffer, 'Babbage's intelligence: calculating engines and the factory system,' *Critical inquiry* 21 (1994): 203-27. For block-making trade see Campbell, *London tradesman*, p. 301.

[30] E. A. Forward, 'Simon Goodrich and his work as an engineer: II,' *Transactions of the Newcomen Society* 18 (1937):1-27, p. 7.

[31] Coad, *Royal Dockyards*, 110; [Dionysius Lardner], 'Babbage's calculating engine,' *Edinburgh review* 59 (1834): 263-327, pp. 313, 319; Charles Babbage, *On the economy of machinery and manufactures*, 4th ed. (London: Charles Knight, 1835), pp. 120-1.

[32] Maxine Berg, *The machinery question and the making of political economy 1815-1848* (Cambridge: Cambridge University Press, 1980), pp. 145-54.

[33] John Charnock, *History of marine architecture*, 3 vols. (London: Faulder, 1800), vol. 3, pp. 52, 107; Pierre Lévêque, 'Préface,' in Jorge Juan, *Examen maritime, théorique et pratique*, 2 vols. (1771; Nantes:

The managerial programme and companion mathematical enterprise have been studied separately as histories of administrative reform and of enlightened rational mechanics. They must be examined together. Mathematical hydrodynamics drew on hydraulics treatises that codified craft practices of the water oeconomy described in this book's previous section. The most significant text in the rational analysis of naval architecture available in Britain was certainly Leonhard Euler's *Complete theory of the construction and property of vessels*, translated in 1776 by the East India Company's military engineer Henry Watson. The link with the Company is suggestive. The growth in high-class teak shipbuilding by Parsi experts in the Bombay and Calcutta yards was increasingly seen as a major threat to the London docks. Watson promoted an expensive scheme for new wet and dry docks at Calcutta from 1772 and used works there to encourage more mathematical training for Company engineers in association with promotion of the lucrative China trade. 'The prosperity of the Company and the Interest of the English Nation are intimately connected with the Construction of Docks in Bengal'. He associated the success of new Indian-built frigates with Euler's text, which provided important resources for managing differences between self-styled mathematical theory and the performance of careful trials. Military engineers were sent back to London to learn how to manage his dockyards. Euler himself conceded his analytical formulae's failings. The performance of carefully scrutinised experiments on geometrically simplified ship models were part of his recipe. Watson added advice to the Admiralty that 'though the subjects are handled scientifically, yet such practical rules for constructing vessels to advantage might be drawn therefrom'. To derive practical lessons from abstract models, however, would certainly require overhauling the details of construction practice.[34]

It is telling that some of the more celebrated naval architectural experimental projects were promoted as part of the state's military-fiscal ambitions to renovate and regulate the work of shipyards and related public works. British analysts envied the French connection between state support for expert mathematical analysis of naval architecture and the alleged superiority of French warships. The magnificent new royal arsenal at Rochefort, commissioned by Colbert in 1666-1670, was understood as a visionary space of disciplinary

Mallasis, Despilly, 1783), vol. 1, p. ix. See Jean-Pierre Séris, *Machine et communication* (Paris: Vrin, 1987), p. 132.

[34] Leonhard Euler, *A complete theory of the construction and properties of vessels* (1776; London: John Sewell, 1790), pp. 251, 256, 7. For Watson see [John Sewell], 'Sketch of the life and character of the late Colonel Henry Watson,' *European magazine and London review* 12 (1787): 497-9; R.H. Phillimore, *Historical records of the survey of India*, 4 vols. (Dehra Dun: Surveyor General of India, 1945), vol. 1, pp. 270-1, 347, 394.

management and royal power.[35] A decade later Colbert ordered a remarkable series of Versailles conferences to confront master carpenters and naval pilots with artificial models of hull designs subject to experimental trial and theoretical debate. These naval conferences were decisive in making construction theory a component of naval administration and the decomposition of dockyard labour.

One protagonist of these conferences was the Basque commander Bernard Renau d'Elissagary, whose work fascinated mathematicians such as Huygens and Bernoulli. Renau invented new means for drawing the lines of the hull using ingenious geometrical instruments and attacked established naval carpenters' 'coarse and faulty practice, which lacks any principle'. The geometrical instruments and ship models deployed at the conferences worked as complex mediators between builders, navigators and administrators. There is little evidence that dockyard practices were substantially transformed as a result; but the state claimed its right to normalise and regulate dockyard work through remote administrative surveillance.[36]

Comparably conflicted relations between ship construction, mathematical analysis, government regulation and the institutions of the military-fiscal state recurred. As Chandra Mukerji points out in her essay here, French canal programmes were peculiarly telling occasions for discussions of these linkages. Engineers contemplated an underground Picardy canal, first proposed in the 1720s, to secure the militarily and economically decisive inland navigation system that might protect trade from the British navy. Work on the canal halted in 1775 as a result of a major public conflict between allies of the reformist minister Turgot and leaders of the royal Corps des Ponts et Chaussées. Turgot recruited the academic analysts Condorcet, d'Alembert and Bossut to test this ambitious hydraulic scheme. Based on trials with ship models to test their favoured hydrodynamic theories and the effects of bow friction, the analysts quashed further work on the canal. Instead of complex hulls, they relied on highly simplified geometrical shapes, taking for granted the dependence of resistance on the square of these models' speeds and claiming that the frictional effects on the sides and stern of their models were negligible. 'It is the geometers, the physicists and the engineers, not the technicians or builders, whose opinion on the underground canal can have any influence on the enlightened'.[37]

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[35] Markus, *Buildings and power*, pp. 258-9.

[36] Colbert is cited in Séris, *Machine et communication*, p. 68; Renau is cited in Vérin, *La gloire des ingénieurs*, pp. 336-38. For dockyard practice and reform see James Pritchard, 'From shipwright to naval constructor: the professionalisation of 18th century French naval shipbuilders,' *Technology and culture* 28 (1987): 1-25, pp. 6-10.

[37] Jean d'Alembert, Marie-Jean Caritat de Condorcet and Charles Bossut, *Nouvelles expériences sur la résistance des fluides* (1777) is cited in Pietro Redondi, 'Along the water: the genius and the theory.

‘Enlightened’ readers closely studied the academicians’ experiments. When the writings of Paul Hoste, hydrography professor at Toulon and veteran of the Versailles conferences, were translated into English in 1762, they carried the message that shipbuilding was ‘the most undetermined and most imperfect of all arts … ships built with the greatest exactness and application often prove the worst, and those which are built without any strict regard to rules answer the purpose much better’.[38] The Scottish shipwright Mungo Murray, who taught mathematics at Deptford and later joined the Royal Navy, produced several editions of the works of French experts and mathematicians on naval architecture. For him, the lesson was clear: ‘the particular form of a ship cannot be determined by rules that will admit of a mathematical demonstration’. Little assisted by mathematicians, builders were forced to rely on experience.[39]

The London naval officer William Falconer, celebrated poet of *The Shipwreck* and compiler of an authoritative maritime dictionary, pointed to the unhealthy relation between mathematical principles and standards and shipwrights’ art. From his perspective, ‘nothing appears more effectually to have retarded the progress of naval architecture than the involving it in mysteries which the professors gravely insinuate are only intelligible to themselves’.[40] A contemporary Deptford apprentice, Marmaduke Stalkartt, published a magnificently illustrated treatise on shipbuilding in 1781 and soon set up his own shipyard at Rotherhithe. Stallkart matched Falconer’s view of naval architecture’s weakness. Wanting to forge an analytical project that would both overhaul dockyard process and introduce principles into naval architecture, he marshalled the terms ‘theory’ and ‘demonstration’ to fortify his criticism. ‘In the Theory of the Art there are no fixed and positive principles, established by Demonstration and confirmed by use. There is a hardly a Rule sanctified by common Consent, but the Artist is left to the Exercise of his own Opinion; and this generally becomes so rooted by Habit as to resist innovation however

D’Alembert, Condorcet and Bossut and the Picardy canal controversy,’ *History and technology* 2 (1985): 77-110, pp. 91, 96. See also W. F. Stoot, ‘Some aspects of naval architecture in the eighteenth century,’ *Transactions of the Institution of Naval Architects* 101 (1959): 31-46, pp. 37-43; Roger Hahn, *L’hydrodynamique au XVIII^e^ siècle: aspects scientifiques et sociologiques* (Paris: Palais de la Découverte, 1965); Keith Baker, *Condorcet: from natural philosophy to social mathematics* (Chicago: Chicago University Press, 1975), pp. 67-69.

38 Paul Hoste, *Naval evolutions*, ed. Christopher O’Bryen (London: Johnston, 1762), pp. 55-56.

39 Mungo Murray, *Supplement to the Treatise on Shipbuilding containing extracts translated from M. Bouguer’s Traité du Navire* (London: Millar, 1765), pp. 3-4.

40 William Falconer, *An universal dictionary of the marine*, new edition (London: Cadell, 1776), s. v. ‘Architecture, Naval’.

specious'. This was how principled innovation was linked with an effort to decompose and regulate the work of artisans.[41]

Historians have concluded that the savants' aim was 'the replacement of a handicraft tradition or craftsman's approach by a scientific one,' but that this proved infeasible. Crucial was the development of novel spaces for training and experimentation where mathematical analysis was cultivated both as an education programme and an enterprise in naval architecture.[42] In his definitive history of the Georgian navy, Nicholas Rodger concludes that British mixed mathematics and informal training systems were at least as effective as enlightened analysis, that some of this analysis was false and the rest almost completely inoperative. Differences in ship performance ultimately depended less on precision design than on maintenance of a clean hull and masters' improvised judgement of rig and trim.[43] Analytic projects of management and hydrodynamics were closely related. Neither was ever entirely successful in Georgian Britain, but both involved careful redrawing of the legitimate map of skill, theory and practice. The production of ship plans with measured scales was a decisive precondition of the relevance of such analytical theory to naval design. This is one reason why the geography of skilled design mattered to the labour process of naval architecture. The relative place of and relation between mould loft and drawing office counted for the status and fate of any ship trial.[44]

A range of strategies was developed by mathematical masters and naval managers in Georgian Britain to link these separate sites, including attempts to render diagrams more precise, adding measured scales and offering detailed specifications of warship types. The aim was to normalise design by movements between the mould lofts and drawing offices. In 1716, for example, the Navy Board ordered the yards' master shipwrights to send them 'a draught or model of such ships as to their dimensions…so that we may inspect thereinto' and to 'draught a solid or model shaped exactly with the load water line, the height of the decks and wales &c marked thereon'. Such proclamations seem

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[41] Marmaduke Stalkartt, *Naval architecture, or the rudiments and rules of shipbuilding* (London: Sewell, 1781), p. i. For his dockyard see Philip Banbury, *Shipbuilders of the Thames and Medway* (Newton Abbott: David and Charles, 1971), pp. 137-8.

[42] Vérin, *La gloire des ingénieurs*, p. 338; Pritchard, 'From shipwright to naval constructor,' pp. 14-15.

[43] Richard Unger, 'Design and construction of European warships in the seventeenth and eighteenth centuries,' M. Arrera, J. Merino and J. Meyer, eds., *Les marines de guerre européennes XVII-XVIII^e^ siècles* (Paris: Presses Universitaires de Paris-Sorbonne, 1986), 21-34, pp. 21-22; Henk Bos, *Lectures in the history of mathematics* (New York: American Mathematical Society, 1993), p. 121; Rodger, *The command of the ocean*, pp. 409-10, 415.

[44] David McGee, 'From craftsmanship to draughtsmanship: naval architecture and the three traditions of early modern design,' *Technology and culture* 40 (1999): 210-36, pp. 215, 225.

rarely to have brought dockyard designs under rigorously standardised norms. Indeed, this was precisely the problem identified by the spy Olivier in his visits to Deptford in the 1730s.[45] In a much-reprinted account of the processes of ship-building, the Deptford master shipwright William Sutherland spelled out the ingenious improvisation involved in forming the ship's frame, which he argued could be made unnecessary were the principles of rational geometry more systematically at work in the dockyards. Sutherland was explicit about the consequences of geometrical control for labour relations. 'Not only the character of accomplish'd shipwrights might soon be attained,' but conversion and training costs would fall dramatically.[46]

The mould lofts therefore became sites of intense struggle around economy, training and mathematical reason. There an outline of each frame would either be drawn in chalk onto a specially designed blackened floor or incised directly into the wood. Models and templates were decisive tools. The lines were scaled up from the models onto the loft floor, then used to make templates or moulds that were carried between the loft and the wood-yards, where they guided the cutting of the frames. The templates acted as mobile models, serving as resources for rather than dictating ingenious skill in the yards. The sociologist David Turnbull reminds us how such templates could help coordinate disparate tasks and aid construction without the singular control of a master plan.[47] The mould lofts were often seen as key centres of this property of skill: traditionally, apprentices articled to the shipwrights in the 'art and mystery' of construction would spend at least two years learning draughtsmanship in the lofts. Nicholas Rodger urges that this training's sophistication was generally equal to more analytical French naval systems. Rather formalised and textual training systems introduced by British managerial reformers at the century's end were criticised within the Admiralty precisely because they would exclude tyros from these lofts, 'where the plans of ships are drawn and where consequently some knowledge might be gained'.[48]

The skilful enterprise of scaling, moulding and cutting in the dockyards was both an opportunity and a provocation for those who wished to govern

[45] Navy Board, 4 June 1716, in John Franklin, *Navy board ship models 1650-1750* (Conway: Maritime Press, 1989), p. 176; compare Brian Lavery and Simon Stephens, *Ship models: their purpose and development from 1650 to the present* (London: Zwemmer, 1995), p. 22.

[46] William Sutherland, *The ship-builder's assistant* (London: Mount and Page, 1766), p. 67.

[47] David Turnbull, *Masons, tricksters and cartographers: comparative studies in the sociology of scientific and indigenous knowledge* (Amsterdam: Harwood, 2000), p. 68.

[48] Coad, *Royal dockyards*, pp. 157-8; Basil Greenhill, *The evolution of the wooden ship* (London: Batsford, 1988), pp. 92-97. For knowledge in the lofts see Haas, *Management odyssey*, pp. 22-24; Rodger, *Command of the ocean*, p. 409; and Morris, *Royal dockyards*, p. 112.

this process in the name of superior analysis and economy. From the surveyors' offices at the Navy Board, based from 1786 at Somerset House in central London, the mould lofts of the dockyards down-river at Deptford or along the coast at Sheerness might well seem frustrating sites of friction, resistance and improvisation beyond their sure control. No naval yard had a unique commander and management relied on the Navy Board's machinations. The Earl of Sandwich, First Lord of the Admiralty, endeavoured to bring naval administration and dockyard labour under centralised management. One of his tactics was to commission models of each of the naval yards and several exemplary ships.[49] The geographical gap between the surveyors' drawing rooms, staffed with former shipwrights turned clerks and analysts, and the dockyard lofts, the workplace of naval carpenters and their apprentices, accompanied the development of drawn plans of ship design. As mathematicians such as Emerson were all too aware, this gap was *a barrier* to the analytical project to direct and standardise naval architecture since it could frustrate the ability of the Board's surveyors to act at a distance. Yet the interval between Board and yards was also *a resource* for the development of a mathematical naval science, since it created worlds on paper where mathematical practice could be applied to manipulable analytical proxies for working ships. This was the place where managerial accountancy and mathematical analysis might work together.

In reaction to the campaign in which Shrubsole took part in the late 1760s, Sandwich sought to break down dockyard labour into separate tasks. Further strikes frustrated this plan, which were only revived during Bentham's inspectorate in the early 1800s.[50] Master shipwrights were formed in committees to draw up analytical tables that anatomised the shipbuilding process from start to finish. The aim was to transform shipbuilding into a 'uniform, efficient and economical system'. Shipwrights resented officers taking daily measurements of their work and countered fiercely that such a regime 'treats them, as if neither time nor expense was required to learn their trade'. There was, thus, an intimate and a polemical relation between the mathematical decomposition of the tasks of naval architecture and the mathematical analysis of the construction and behaviour of the warships.[51]

[49] Nicholas Rodger, *The insatiable Earl: a life of John Montagu, fourth earl of Sandwich* (London: Harper Collins, 1993), p. 139; Miles Ogborn, *Spaces of modernity: London's geographies 1680-1780* (New York: Guilford Press, 1998); Lavery and Stephens, *Ship models*, pp. 36-37.

[50] *Ibid.*, pp. 150-154.

[51] Haas, *Management odyssey*, pp. 35-36, 55; Morriss, *Royal dockyards*, pp. 205-8; Ashworth, 'System of terror,' p. 77; 'Case of the shipwrights', *Mechanics' Magazine*, 21 (1823): 107 (11 October 1823).

It was not until the period of Bentham's tenure as Inspector that a programme of naval architecture developed which hinged on the spatial distinction between the work, income and status of metropolitan designers and those of dockyard shipbuilders downriver.[52] What matters here is how the term 'theoretical knowledge' came to be associated with designers' work.[53] This was neither an inevitable nor a monotonic process of displacing wood and metal by paper and ink in the name of abstraction and accuracy. It was in these attempts to distinguish geographically between sites of design and construction, while forging reliable relations of management and subordination between them, that theory, practice, calculation, friction and resistance – key terms of naval architecture – gained their meaning.

It is significant, therefore, that an important metropolitan naval enterprise of the 1790s that frequently discussed such terms began as a *publishing venture* aimed at remodelling naval architecture on paper, then developed into an *experimental project* to try ship models in the docks. During the early years of struggle against the French republic, when British naval power did not seem assured and metropolitan analysts were highly active in proposing reform schemes for mathematical modelling of ship design and dockyard management, the newly launched Society for the Improvement of Naval Architecture played an ambitious role as social network and knowledge store within the reformulation of dockyard labour.[54] The Society's plans were symptomatic of the aims and interests of metropolitan analysts and administrators in forging new spaces for naval architecture.

Members, under the leadership of the London publisher John Sewell and presidency of the future William IV, tended to be anti-French and anti-labour, but highly favourable of establishing a 'scientific' regime that would bring order to naval architecture and dockyard business. Sewell's Society set out to build a set of enterprises in London that they reckoned could weld a new alliance of expertise to reorganise, then rationalise, dockyard practice. Decisive was the Society's ability to recruit interest among the major private shipyard owners, notably the Rotherhithe masters John Randall and William Wells, whose works supplied much of the labour for the East India Company's

[52] McGee, 'From craftsmanship to draughtsmanship,' p. 225 n. 40. On paperwork and the sites of ship design see Stephen Johnston, *Making mathematical practice: gentlemen, practitioners and artisans in Elizabethan England* (PhD thesis, Cambridge University 1994); the general issues of paper plans are described in Peter Booker, *History of engineering drawing* (London: Chatto and Windus, 1963), pp. 16-22.

[53] Unger, 'Design and construction of European warships,' p. 23.

[54] A. W. Johns, 'An Account of the Society for the Improvement of Naval Architecture', *Transactions of the Institution of Naval Architects* 52 (1910): 28-40.

largest ships.[55] The Society was directly responsible for fomenting the view of innate and threatening French superiority in speedier warships, diagnosing this as a result of state support for academic hydrography. The implication was clear. The Society would simultaneously accumulate texts and models for public display in the City, pay for large-scale model trials in the yards of the Rotherhithe builders and agitate publicly for the foundation of a new naval architecture academy under government administration where proper attention would be given to mathematics.[56]

The School of Naval Architecture was finally established along these lines in the Portsmouth naval yards in 1811.[57] Generally, the Society's initiatives set out a specific and polemical account of the right relation between theory and practice, then put the power of mathematical analysis and controlled experiment in spaces designed to model and regulate the work of traditional dockyard custom. The insistence on regular geometrical forms in hull design, the importance of establishing a viable solid of least resistance and the mathematical analysis of friction, all depended on explicitly overhauling the work done in mould lofts and wood yards. Euler's careful description of how to conduct model trials was republished. So were the appropriate passages on the primacy of 'theory' drawn from the writings of Emerson, Atwood and Charnock. Even though Emerson had foresworn his project to define the solid of least resistance, the Society reprinted its analytical details in its widely distributed publications.[58]

A clever and wealthy young London FRS, heir to a Lambeth brewery and much enthused by the application of mathematical analysis to shipbuilding, Mark Beaufoy, soon joined the Society. He at once summarised and criticised the 1775 trials run by Bossut and his colleagues in Paris. Beaufoy proposed increasing the trials' scale, reordering the means through which geometrical models were drawn through the water, assessing frictional effects with far more precision and recruiting both shipbuilders and mathematicians to the cause. With the Society's aid, this was precisely what Beaufoy and his allies did. Beaufoy's trials cost him almost £30,000 and lasted from 1793 until the Socie-

[55] For Sewell's career see John Nichols, *Literary anecdotes of the eighteenth century*, 6 vols. (London: Nichols, 1812), vol. 3, pp. 737-9; Ian Maxted, *The London book trades 1775-1800* (London: Dawson, 1977), p. 201. For the formation of the Society see *Collection of papers on naval architecture,* vol. 1 (London: Sewell, 1791-2), part 1, pp. iii-viii, 63-66.

[56] *Collection of papers,* vol. 1, part 1, pp. 2, 14-15.

[57] This is the view of George Cornelius Gorham, *Memoirs of John Martyn and Thomas Martyn, professors of botany* (London: Hatchard, 1830), p. 204.

[58] *Collection of papers* vol. 1, part 1, pp. 27-28 (Euler); *Collection of papers on naval architecture,* vol. 2 (London: Sewell, 1798-1800), part 1, pp. 39-41 (Emerson), part 3, pp. 1-11 (Atwood), and part 3, pp. 33-39 (Charnock).

ty's extinction in late 1798. William Wells, another Society member, gave him use of the large Greenland Dock, and his collaborators included naval officers, the pre-eminent East India dock manager John Randall and the naval professor Charles Hutton, who performed the tedious calculations to derive precise results from the vast amount of data accumulated in Beaufoy's almost two thousand separate experiments.[59]

From the start of 1795 Beaufoy's attention turned to the effects on motion when the models were submerged. By winter 1795-96 he could demonstrate that friction was a major and quantifiable factor in motion. Against the orthodoxy of Newton, Bossut and Euler, it seemed that the bow shape was not the only factor affecting ship performance. Beaufoy sought counsel from expert allies in the Society, who helped him define fluid resistance as a combination of the pressure effects at bow and stern, plus the friction along the surface of the hull. Beaufoy introduced what he called 'friction planks' to show that in general speed varied with resistance at a power of speed of between 1.71 and 1.82, well below the Newtonian square law.[60] Soon after Beaufoy completed his runs, his equipment was taken over by other Society members. Charles Gore, a Lincolnshire landowner and marine artist, with strong connections with the court of Weimar, joined in the Society's experimental programme. Armed with trial data showing that curved hulls were the most stable and that ships could be designed much longer than they were wide, Gore and his friends at Greenland Dock hoped 'that in time those absurd maxims which have so long governed the constructors of shipping will submit to refutation and be laid aside'.[61]

This was fatally overoptimistic. Making Beaufoy's trial models count as exemplars of shipyard realities and capable of changing shipwrights' ways, required more than experimental efforts at Wells' yard at Greenland Dock and Hutton's desktop calculations at Woolwich. In fact, it required an entire transformation of the labour conditions and administrative structure of the dockyards and the academies. With Beaufoy and Sewell's prompting, Atwood responded to the Greenland Dock work with a Royal Society paper that

[59] For Beaufoy's first experimental project see *Collection of papers,* vol. 1, pp. 24-27; his later work is first described in *Report of the Committee for conducting the experiments of the Society for the Improvement of Naval Architecture* (London, ?1798), pp. i- ii. For details, see Thomas Wright, 'Mark Beaufoy's nautical and hydraulic experiments,' *Mariner's mirror*, 75 (1989): 313-327.

[60] Mark Beaufoy, *Nautical and hydraulic experiments*, ed. Henry Beaufoy (London: privately printed, 1834), pp. xxvii-viii; Wright, 'Mark Beaufoy's experiments,' pp. 317-21.

[61] Charles Gore, *Result of two series of experiments towards ascertaining the respective velocity of floating bodies…in a letter to the Society for the Improvement of Naval Architecture* (London: Hayward, 1799), pp. 5-6. Gore's work is first noticed in *Collection of papers on naval architecture,* vol. 1, part 3, p. 162 (10 September 1792).

surveyed the entire tradition of navigational science since Euler. He proposed large-scale tests to account for the differences and distance between analytical theory and shipwrights' customs. Atwood was especially struck by Beaufoy's demonstrations that stern pressure and hull friction were real and potentially quantifiable factors in ship motion, or at least in the motion of his geometrical solids. They showed, Atwood claimed, that frictional resistance must be at least a cubic equation in velocity. The complete failure of prior analysts to recognise these facts was not, according to Atwood, a sign of the global irrelevance and futility of rational mechanics. On the contrary. Atwood carefully distinguished two senses of the term 'theory': the academic mathematicians' 'pure laws of mechanics' and 'a systematic rule which individuals form to themselves from experience and observation alone'. He was quite prepared to credit the 'experimental knowledge in naval constructions which has been transmitted from preceding times,' matters of the shipwrights' 'skill and ingenuity'. He recognised that 'skilful practice aided by long experience arrives at determinations which it is very difficult, sometimes impossible, for theory to infer'. But their difficulty in *inferring* shipyard tradition had no effect, apparently, on analysts' rights to *direct* the shipwrights. Once again, the Newtonian hierarchy of reason over custom was asserted. The hierarchical alliance between rational analysis and experimental modelling was the only means through which naval systems' global reach could be engineered.[62]

Though unwieldy and abstract, Atwood's methods were adopted as guides in the Navy. In early 1798, as Beaufoy's experiments were reaching completion and Wells' yard shut, Atwood published a treatise on ship stability. He claimed the right to discriminate 'principles of construction and management…which are founded in truth and right principles, from others which have been the offspring of vague and capricious opinion, misinterpretation of fact and unfounded conjecture'. The politics of rational mechanics were made explicit. Nothing that happened in the shipyards or at sea had ever falsified the true theory of motion. The sole reason for the apparent inapplicability of theory was the danger of failure in experimental trials, their enormous cost and 'steady adherence to practical methods rendered familiar by usage which creates a disposition to reject, rather than to encourage, proposals of innovation in the constitution of vessels'. In fact it might take as long as *two years* to determine ships' centres of gravity and buoyancy using the methods these analysts proposed. This was but one among many of the factors that made it hard to

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62 Atwood, 'Construction and analysis of geometrical propositions,' pp. 125-129. Sewell view is in *Collection of papers on naval architecture,* vol. 1, p. vii.

deduce proper conduct in the shipyards, or at sea, from the calculations of rational mechanics.[63]

Atwood's programme can well be compared with the contemporary attempts by Bentham and his allies at Portsmouth, where the principles of rational mechanics and precision engineering were applied to break the shipwrights' resistance, subject them to severer labour discipline and transform dockyard production lines. Violent resistance to labour decomposition and the new system of analytical theory in the dockyards was not limited to the Portsmouth strikes against Bentham's system. To demonstrate the workability of his own project, Atwood contacted the shipyard contractors, Randall and Brent, who had helped administer Beaufoy's trials. They supplied him with schemes of a fine East India ship to test his model of stability and loading.[64] John Randall, head of the Rotherhithe firm, was the main supplier of ships to the East India Company. He planned his own treatise on naval architecture through the medium of the Society for the Improvement of Naval Architecture before being forestalled by Atwood and Beaufoy. In spring 1802, as the navy demobilised at the end of the Revolutionary War, Randall tried to impose a wage cut in his yards. His workers went on strike and Randall tried to get scab labour from the Deptford royal dockyards nearby down the Thames. The Admiralty offered troops to guard Randall's yard and sacked their own men who refused to work there. This was the major labour crisis of the age, leading directly to Randall's death and victory for the shipwrights. The shipwrights themselves referred to the 'mystery' of their triumph.[65] Unlocking the mystery of the shipwrights was precisely the concern of yard managers, model experimenters and academic theoreticians.

The Society for the Improvement of Naval Architecture ceased amidst fiscal chaos in 1801. Beaufoy's apparatus was sold off to help pay booksellers to distribute his numbers. His model data were only fully published in 1834, prefaced with a eulogy of Randall and an account of his death during the 1802 strike.[66] After the strike Beaufoy, now a loyal officer of the national militia, long continued his campaign for naval modelling and the complete overhaul of ship design in the Thames yards. Convinced especially by his ingeniously

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63 George Atwood, 'Disquisition on the stability of ships', *Philosophical transactions* 88 (1798): 201-310, pp. 202-4. For the unwieldy quality of Atwood's methods, see McGee, 'From craftsmanship to draughtsmanship,' pp. 231-33.

64 Atwood, 'Disquisition,' p. 287.

65 *The Times* (24 August 1802); Iorwerth Prothero, *Artisans and politics in early nineteenth century London* (Folkestone: Dawson, 1979), pp. 47-48; Roger Morris, 'Labour relations in the dockyards 1801-5,' *Mariner's mirror*, 62 (1976): 337-346. For Randall's career see Banbury, *Shipbuilders of the Thames*, pp. 133-6.

automatic devices of precision measure of velocity, Beaufoy urged the dedicated production of experimental vessels with perfected geometrical lines under the immediate supervision of scientifically expert officers. The aim, he charged, was 'to expel the mist that at present envelops the science of hydrodynamics,' backed with Navy Board supervision and Treasury support.[67]

Such programmes to clear the mists of tradition and automate the recording of time and design characterise the aims of the powerful alliance of mathematical practitioners, accountants, managers and the professoriate which forged new sets of administrative and scientific institutions in the period of the French wars and their immediate aftermath. Men such as Atwood, Babbage and Beaufoy were protagonists of this enterprise. Theirs was the alliance responsible for the rapid emergence of new forms of physical sciences in late Georgian Britain.[68]

The aim of this essay has been to use the polemical career of naval architecture to explore the political geography of such an alliance, especially its attempt to overhaul the systems of shipwrights' work along the Thames. In early 1793, as Beaufoy began his remarkably engineered trials at the new experimental space of East India dockyards downriver, another keen observer of metropolitan struggle composed a vision of the future of work and society along the great river. Right by Beaufoy's former home in Lambeth, the visionary artist William Blake wrote these lines in his commonplace book:

Why should I care for men of thames
Or the cheating waves of charter'd streams
Or shrink at the little blasts of fear
That the hireling blows into my ear.

Within a few months, the verses became one of Blake's greatest *Songs of Experience*, 'London'. He sang of 'mind-forg'd manacles' and 'the charter'd Thames'. The relation between river, charter and imprisonment was deliberately designed by Blake to summon images of metropolitan commerce, Sewell's anti-Republican Loyalist Societies and the aggressive trading companies along the river, especially the newly-chartered East India Company and its dockyard allies.[69]

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66 Beaufoy, *Nautical and hydraulic experiments*, p. xxxviii; the collapse of the Society is documented in National Maritime Museum MSS Soc 17 (especially the Resolution of 9 December 1800).

67 Mark Beaufoy, 'Suggestions for building experimental vessels for the improvement of the Navy,' *Annals of philosophy*, 10 (1817): 256-264, p. 262.

68 David Phillip Miller, 'The revival of the physical sciences in Britain 1815-1840,' *Osiris* (1986): 2: 107-134; William B. Ashworth, 'The calculating eye: Herschel, Babbage and the business of astronomy,' *British journal for the history of science*, 27 (1994): 409-42.

69 William Blake, 'Thames' (1793) and 'London' (1793-4), in Geoffrey Keynes, ed., *Blake: complete writings* (Oxford: Oxford UP, 1972), pp. 166 and 216. My reading follows David Erdman, *Blake:*

Blake's millenarian vision, like that of Shrubsole's paean to shipwrights' 'Immortal Reason' two decades earlier, was a telling vision of what was at stake in the architecture, geography and experience of maritime life in an age of revolution. The poet may never have encountered the experts of the Society for the Improvement of Naval Architecture. But he offered a brilliant analysis of the world where such practical theorists flourished.

Primary sources

Anderson, Robert, *Genuine use and effects of the gunne* (London: Berry and Morden, 1674).

Anon., 'Case of the shipwrights', *Mechanics' Magazine* 21 (1823): 107.

Anon., 'Observations on naval architecture and on the state of science in our dock-yards,' *Quarterly journal of dcience, literature and the arts* 18 (1825): 320-22

Anon., 'Naval architecture,' *The Chemist* 2 (1825): 349-51, 428-30.

Atwood, George, 'The construction and analysis of geometrical propositions assumed by homogeneal bodies which float freely, and at rest, on a Fluid's surface: also determining the Stability of Ships and of other floating bodies,' *Philosophical Transactions* 86 (1796): 46-130.

Atwood, George, 'Disquisition on the stability of ships,' *Philosophical Transactions* 88 (1798): 201-310.

Babbage, Charles, *On the economy of machinery and manufactures*, 4th ed. (London: Charles Knight, 1835).

Baily, Francis, *An account of the Reverend John Flamsteed* (London: Admiralty, 1835).

Beaufoy, Mark, 'Suggestions for building experimental vessels for the improvement of the Navy,' *Annals of philosophy* 10 (1817): 256-64.

Beaufoy, *Nautical and hydraulic experiments*, ed. Henry Beaufoy (London: privately printed, 1834).

Blake, William, *Blake: complete writings*, ed. Geoffrey Keynes (Oxford: Oxford University Press, 1972).

Campbell, R., *The London tradesman* (London: T. Gardner, 1747).

Charnock, John, *History of marine architecture*, 3 vols. (London: Faulder, 1800).

Collection of papers on naval architecture, vol. 1 (London: Sewell, 1791-2) and vol. 2 (London: Sewell, 1798-1800).

Defoe, Daniel, *A tour through the whole island of Great Britain*, ed. Pat Rogers (1724; Harmondsworth: Penguin, 1971).

Euler, Leonhard, *A complete theory of the construction and properties of vessels* (1776; London: John Sewell, 1790).

Emerson, William, *Principles of mechanics* (London: Innys and Richardson, 1754).

Emerson, William, *Principles of mechanics*, 2nd ed. (London: Innys and Richardson, 1758).

Emerson, William, *Mechanics or the doctrine of motion* (London: Nourse, 1769).

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prophet against empire, 3rd ed. (Princeton: Princeton University Press, 1977), pp. 273-278 and E. P. Thompson, *Witness against the beast: William Blake and the moral law* (Cambridge: Cambridge University Press, 1993), pp. 174-180. For Blake and the Atlantic maritime workforce in the 1790s see Linebaugh and Rediker, *Many headed hydra*, pp. 351-3.

Falconer, William, *An universal dictionary of the marine*, new edition (1769, London: Cadell, 1776).
Flamsteed, John, *Correspondence of John Flamsteed*, ed. Eric Forbes, Lesley Murdin and Frances Willmoth (Bristol: Institute of Physics, 1995-2001), 3 vols.
Galilei, Galileo, *Mathematical discourses concerning two new sciences* (London: Hooke, 1730).
Galilei, Galileo, *Two new sciences*, ed. Stillman Drake (1638; Madison: University of Wisconsin Press, 1974).
Gore, Charles, *Result of two series of experiments towards ascertaining the respective velocity of floating bodies…in a letter to the Society for the Improvement of Naval Architecture* (London: Hayward, 1799).
Gorham, George Cornelius, *Memoirs of John Martyn and Thomas Martyn, professors of botany* (London: Hatchard, 1830).
Hoste, Paul, *Naval evolutions*, ed. Christopher O'Bryen (London: Johnston, 1762).
Hutchinson, William, *Treatise on practical seamanship* (Liverpool: for the author, 1777).
[Lardner, Dionysius], 'Babbage's calculating engine,' *Edinburgh Review* 59 (1834): 263-327.
Lévêque, Pierre, 'Préface,' in Jorge Juan, *Examen maritime, théorique et pratique*, 2 vols. (1771; Nantes: Mallasis, Despilly, 1783).
Murray, Mungo, *Supplement to the Treatise on Shipbuilding containing extracts translated from M. Bouguer's Traité du Navire* (London: Millar, 1765).
Newton, Isaac, *Principia mathematica, the third edition with variant readings*, ed. Alexandre Koyré and I. Bernard Cohen (1726; Cambridge: Cambridge University Press, 1972).
Newton, Isaac, *The Principia*, translated by I. Bernard Cohen and Anne Whitman (Cambridge: Cambridge University Press, 1999).
Newton, Isaac, *Correspondence of Isaac Newton*, ed. H.W. Turnbull, J. F. Scott and A. R. Hall (Cambridge: Cambridge University Press, 1959-77), 7 vols.
Nichols, John, *Literary anecdotes of the eighteenth century*, 6 vols. (London: Nichols, 1812).
Olivier, Blaise, *Eighteenth century shipbuilding: remarks on the navies of the English and Dutch by Blaise Olivier*, ed. David H. Roberts (Rotherfield: Boudriot, 1992).
Report of the Committee for conducting the experiments of the Society for the Improvement of Naval Architecture (London: Society for the Improvement of Naval Architecture, ?1798).
[Sewell, John], 'Sketch of the life and character of the late Colonel Henry Watson,' *European Magazine and London Review* 12 (1787): 497-9.
Shrubsole, William *A plea in favour of the shipwrights belonging to the Royal Dock Yards* (Rochester: Fisher, 1770).
Stalkartt, Marmaduke, *Naval Architecture, or the rudiments and rules of ship building* (London: Sewell, 1781).
Sutherland, William, *The ship-builder's assistant* (London: Mount and Page, 1766).
Venn, Thomas, *Military and maritime discipline* (London: Pawlett, 1672).
Vitruvius, *Ten books on architecture*, ed. Morris Hicky Morgan (Cambridge, MA.: Harvard University Press, 1914).

IV. Art and industry

Introduction

Simon Schaffer

Looking back to his own hands-on training in Edinburgh in 1817-1820, the eminent engineer James Nasmyth protested against the mindful hand's displacement by a regime of formal texts and fashionable society. He wrote:

> The truth is, the eyes and fingers – *the bare fingers* – are the two principal inlets to sound practical instruction. They are the chief source of trustworthy knowledge in all the materials and operations that the engineer has to deal with. No *book* knowledge can avail for that purpose. The nature and properties of materials must come in through the finger-ends; hence I have no faith in younger engineers who are addicted to wearing gloves. Gloves, especially kid-gloves, are non-conductors of technical knowledge.

Nasmyth here put forward an increasingly nostalgic commonplace view of the overwhelming significance of locally embodied skill. Yet he was in fact much associated with the intensive mechanisation of the production process and the deployment of ingenious machines against workforce recalcitrance. On these occasions, the gloves were off. 'Free trade in ability' and 'self-acting machines' were Nasmyth's tools for quelling trades disputes and labour resistance: in his political vocabulary, to be loyal and virtuous was to be *handy*.[1] We need to make sense of this telling contrast between formal knowledge, often identified with the categories of science and rational philosophy, and 'finger-ends' skills, equally often coupled with the enterprise of artisans and technicians. This is especially necessary because, as Nasmyth's remarks remind us, the distinction was articulated by those who sought to use machines as weapons and to wield knowledge as power.

The previous section of our book showed how the ownership and the meaning of goods and skills constructively depended on the spaces where they were made and used. Here our attention shifts to the problems of mobility

[1] Samuel Smiles, ed., *James Nasmyth, engineer: an autobiography* (New York: Harper, 1883), pp. 99-100, 226-228. Compare A.E. Musson, 'James Nasmyth and the early growth of mechanical engineering,' *Economic history review* 10 (1957): 121-127.

within and between such spaces. The translation of skills and the movement of commodities have been signal concerns for historians of eighteenth century commerce and industry, just as for eighteenth century practitioners themselves. These interests in how to make goods and techniques robust enough to be moved around were evident even and particularly in the realm judged most relevant to that of knowledge, the domain of print. Many protagonists of the print trades claimed then, as some do now, that texts were stable and transportable embodiments of knowledge, precisely because the work of mechanisation and of its associated standardisation made them so. Yet it was never entirely clear that the outputs of the print shops were indeed immutable and mobile.[2] Rather, considerable manual labour and artful industry was required simply to maintain the identity and reliability of such seemingly secure and translatable goods. The very notions of private and public goods were at stake in these enterprises. Conceptions of property and of social order hinged on the ways in which commodities and practices could be stabilised, regulated and displaced. Concerns with mobility of goods and techniques thus depended on highly fraught notions of the role of art and of industry in the later eighteenth and early nineteenth centuries.

The essays gathered in this section therefore accompany reflections on the various ways in which public knowledge and goods became mobile with lessons about the terms in which contemporaries made sense of changes in the public status of skill and labour. The vocabulary which Nasmyth found so useful, the terms that helped him state the difference between manual training and book-learning, were very much in question in this period. At the start of his brilliant study of notions of culture in and after the Industrial Revolution, Raymond Williams explained how 'industry' and 'art' had both once referred to notions of skill and diligence, to be pursued by 'industrious' artists and artisans. Then, in the final decades of the eighteenth century, *Industry* became more specifically the name of the institutions of production and manufacture, to which new terms such as 'industrial' and 'industrialism' could now be applied. At exactly the same period, *Art* began to be confined to the work of imagination and taste, and would be firmly contrasted to the achievements of mere 'operatives'. In English vocabulary at least, creative and genial Artists would thenceforth be distinguished from other craftsmen and artisans. Williams plausibly identifies these shifts with changes in notion of class and cul-

[2] Compare the remarks on print stability in Bruno Latour, 'Visualization and cognition: thinking with eyes and hands,' *Knowledge and society: studies in the sociology of culture past and present*, 6 (1986): 1-40 with Adrian Johns, 'The ambivalence of authorship in early modern natural philosophy,' M. Biagioli and P. Galison, eds., *Scientific authorship: credit and intellectual property in science* (New York: Routledge, 2003), pp. 67-90.

ture, and finds innovations in notions of industry and art in the crucial period of the machinery question and its urgent significance for the political economy of social and cognitive change. Especially significant here was the fraught system of patenting, which could scarcely guarantee reliable intellectual property to owners without enormous efforts of expense and public demonstration. In the public spheres of machine showrooms and law-courts, as well as in the factories and workshops, a new map was made that would ingeniously redefine private property in terms of heroic invention and the rights of proprietorial manufacturers. It would also significantly shift the enterprise of invention and manufacture into the system of state regulation and social order.[3]

The uses of these terms became apparent whenever trade mobility and commercial property was in question. In 1713, debating cross-Channel dominance of the trade in fine paper, the British Parliament learnt that 'the common people in France are naturally *industrious*'.[4] This Gallic industry apparently explained their market leadership and the consequent flow of fine papers into Britain. Less than a century later, the same word was used but to very different effect by the former Lancashire ironworks clerk and mathematics teacher John Barrow. Veteran of a frustrated 1793 British trade delegation to China, Barrow was keen to explain to his readers what was wrong with the arts and industry of the Qing empire. '*Industrious* they certainly are, but their labour does not always appear to be bestowed with judgement'. Having signally failed to convince the Chinese administrators of the virtue of opening their Empire to freer flow of British manufactures, Barrow and his colleagues judged China an industrious but not an innovative society: 'the people discover no want of genius to conceive, nor of dexterity to execute, and their imitative powers have always been acknowledged to be very great'.[5] Languages of art and industry thus played an important role in helping define the public places of labour, commerce and intelligence. Consider how, in the *Encyclopédie*, 'artistes' and 'artisans' were distinguished through the former's higher intelligence: watchmakers were artists, shoemakers mere artisans. In describing the 'Arts', Diderot notoriously evoked the 'naked hand, as robust, tireless and supple as it may be'.

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[3] Raymond Williams, *Culture and society 1780-1950* (1958; Harmondsworth: Penguin, 1961), pp. 13-16. For the new map of invention, see Christine MacLeod, *Inventing the Industrial Revolution: the English patent system 1688-1800* (Cambridge: Cambridge University Press, 1988).

[4] Torriano's speech in the House of Lords, 1713, is cited in Leonard Rosenband, 'Becoming competitive: England's papermaking apprenticeship, 1700-1800,' in this volume.

[5] John Barrow, *Travels in China* (London: Cadell and Davies, 1804), pp. 566, 306. For Barrow on China see Michael Adas, *Machines as the measure of men: science, technology and ideologies of Western dominance* (Ithaca: Cornell University Press, 1989), pp. 177-183.

Without what he there called 'instruments and rules,' he reckoned this hand powerless to achieve its ends. In many striking ways, this prosthetic notion of technique, superadded to the human hand, underwrote new hierarchies of labour and capital. Some forms of socialisation, knowledge and reason could apparently direct and empower labouring hands for public welfare. Henceforth, in the name of inspired art and solid industry, a language was developed in which labour power was characterised as a stabilised and standardised component of the production process, while the realities of invention and technical progress would be located in the apparently transparent and well-regulated workplace.[6]

Inheritors of this vocabulary, we need to understand its roots and purposes. It is not our intention systematically to retrace familiar if tortuous paths between scientific knowledge and technical innovation in that period. The economic historian Peter Mathias judged three decades ago that this was a story of general attitudes not local knowledge: 'together both science and technology give evidence of a society increasingly curious, increasingly questing, increasingly on the move, on the make, having a go, increasingly seeking to experiment, wanting to improve'.[7] Thanks to their enlightened spirit, it has been argued, French engineers abandoned models of natural order for interventionist analysis, and for the same reason, according to economists of science, British industrialists applied the enlightened scientific method to workshops and factories. The emergence of a German chemical community in the late eighteenth-century has equally been attributed to moods of Enlightenment style and rational-utilitarian attitudes.[8] It is because of similar currents in the moral climate, no doubt, that the sociability of enlightened entrepreneurs, in clubs, academies and correspondence networks, has drawn attention in studies of the new spirit of the age. In his magisterial account of a distinctively English Enlightenment, Roy Porter summed up: science 'broadened horizons and bred hope', its culture spread throughout the land,

[6] William H. Sewell, *Work and revolution in France: the language of labor from the old regime to 1848* (Cambridge: Cambridge University Press, 1980), pp. 66 and 23; Barry Barnes and Steven Shapin, 'Head and hand: rhetorical resources in British pedagogical writing 1770-1850,' *Oxford Review of Education* 2 (1976): 231-254.

[7] Peter Mathias, *The transformation of England* (London: Methuen, 1979; first published 1972), p.66.

[8] Antoine Picon, 'Towards a history of technological thought,' Robert Fox, ed., *Technological change* (Amsterdam: Harwood Academic, 1996), pp. 37-49, p. 45; G.N. von Tunzelmann, 'Technological and organizational change in industry during the Industrial Revolution,' Patrick O'Brien and Roland Quinault, eds., *The Industrial Revolution and British society* (Cambridge: Cambridge University Press, 1993), pp. 254-82, pp.260-1; Karl Hufbauer, *The formation of the German chemical community 1720-1795* (Berkeley: University of California Press, 1982), pp.17-29. On Hufbauer's view of German chemistry, see Ursula Klein's essay in this volume.

societies in Birmingham, Derby, Manchester and elsewhere were its beacons, while 'writers and artists encultured industrialisation'. Ultimately, entrepreneurs such as Josiah Wedgwood and his colleagues became culture heroes in the popular prints and 'the businessman might thus figure as Britain's answer to the enlightened absolutist'.[9]

So social historians invoke atmospheric shifts in the broadly diffused culture of improvement and optimism while historians of industry attend to the enormous difficulties of shifting specific skills and items of practical knowledge so crucial for industrial technique. Mathias urged that 'virtually all recorded instances of transfer of new equipment, the invariable mechanism of diffusion, involved the emigration of skilled artisans and fitters' because 'technology was so specifically embodied in the persons of the skilled artisans'.[10] Hence arose a socially and historically consequential contrast, between seemingly mobile formal knowledge, often identified with the Encyclopedists' rational philosophy, and highly localised embodied knowledge, identified with artisan know-how. It was as though the public culture and published knowledge of enlightenment could travel easily and were thus grander, while the realm of the autochthonous crafts was set in place, so judged lowly. Such attitudes were in question, as example, in an academic memoir on the reform of paper-making published in 1778 by the French manufacturing inspector Nicolas Desmarest: 'government officials know well that workers read very little but observe narrowly and imitate readily…it is thus that the paper industry is to be transformed by a revolution that is called for in the interests of commerce and that will be helpfully forwarded by the zeal and enlightenment of certain manufacturers'.[11]

Yet the opposite map was as easily drawn, a contrasting picture of formally codified rationality and idealised model systems difficult to apply effectively outwith erudite milieux, as opposed to the travelling artisans and entrepreneurs who carried with them across Europe the ability to run engines and promote technological change. Several historians perceptively stress the difficulty of describing, let alone managing and changing, craft skills with encyclopaedic means.[12] One

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9 Roy Porter, *Enlightenment: Britain and the creation of the modern world* (London: Penguin Books, 2001), pp. 149, 427-32.

10 Peter Mathias, *Transformation of England*, p.36.

11 Nicolas Desmarest, 'Second mémoire sur la papéterie,' *Memoires de l'Académie Royale des Sciences* (1774, pb.1778), Charles Coulston Gillispie, *Science and polity in France at the end of the old régime* (Princeton: Princeton University Press, 1980), p.445. Compare Leonard Rosenband, 'Nicolas Desmarest and the transfer of technology in old regime France,' Karen Merrill, ed., *The modern worlds of business and industry: cultures, technology, labour* (Turnhout: Brepols, 1998).

12 Roger Hahn, 'Science and the arts in France: the limitations of an encylopedic ideology,' *Studies in eighteenth-century culture*, 10 (1981): 77-93, p.89; John Harris, 'Skills, coal and British industry in the eighteenth century', *History* 61 (1976): 167-82.

French government administrator, reflecting on the ambitions of entrepreneurs and inventors, condemned in 1783 the 'self-styled artist, unworthy of enlightened protection, who furtively slips into the safe haven of the sciences and arts'. Meanwhile, communal solidarity and the tramping system enabled potent collaboration and translation between groups of skilled craftsmen. This has prompted several historians of technology to characterise what they call 'open techniques,' skilled practices that could travel rather well through the crucial work of mediators, entrepreneurs and merchants.[13] Such histories challenge notions of rooted embodiment in the name of an account much more attentive to the geographies and languages of transfer and translation. So fluid gradations of knowledge and skill, of immobility and communication, especially as perceived by the contemporaries of enlightenment, need careful analysis. Sociologists of scientific knowledge teach us of the embodiment of skill in expert persons and the capricious but effective manner in which skills and techniques travel through these persons' journeys. In particular, just as workshops must be seen as homes of reliable and communicable knowledge, so the image of skilled art has to be applied to the elite sciences. Embodiment and expertise mattered just as much in laboratories as in workshops, ingenuity present both in showrooms and shops.[14]

Hierarchies of knowledge long depended on these seeming contrasts between cloistered stasis and enlightened flexibility, as the opening sections of our book indicate. Issues of machine-like performance and embodiment of skill were fought out in many eighteenth-century industrial sectors. In 1765, a French state inspector of artillery manufacture reported that 'one must not let [the worker] know that he is necessary, that one has need of him. The worker is a kind of stubborn animal who recoils exactly when one wishes him to advance'. Fraught struggles about standardisation and mechanisation characterised much of this kind of enterprise.[15] In Etruria, the entrepreneur and manufacturer Wedgwood sought somehow to turn his potters into reliable machines. He eventually entered the fellowship in the Royal Society for his pyrometer, a device he judged capable of displacing individual artisan

[13] Liliane Hilaire-Pérez, *L'Invention technique au Siècle des Lumières* (Paris: Albin Michel, 2000), p. 164 and Liliane Hilaire-Pérez and Catherine Verna, 'Dissemination of technical knowledge in the middle ages and the early modern era,' *Technology and culture* 47 (2006): 536-565 on p. 540.

[14] S.R. Epstein, 'Journeymen, mobility and the circulation of technical knowledge, 14th-18th centuries,' in Liliane Hilaire-Pérez and Anne-Françoise Garçon, eds., *Les chemins de la nouveauté: inventer, innover au regard de l'histoire* (Paris: CTHS, 2004), pp. 411-430; John Rule, *The labouring classes in early industrial England 1750-1850* (London: Longman, 1986), pp.134-38; Maxine Berg, *The age of manufactures 1700-1820* (London: Fontana, 1985), pp. 282-286.

[15] Ken Alder, *Engineering the revolution: arms and enlightenment in France 1763-1815* (Princeton: Princeton University Press, 1997), p.180.

judgement by replicable mechanical consistency. Adam Ferguson, leading philosopher of the Scottish enlightenment, opined in 1767 that 'many mechanical arts require no capacity…Manufactures prosper most where the mind is least consulted and where the workshop may, without any great effort of imagination, be considered as an engine the parts of which are men'. Such remarks were common in the very institutions where skilled crafts, the ineffable property of groups of artisans, were decisive for production and trade.[16] The contoured categories of knowledge and skill used to make sense of industrialisation thus developed and mutated in that same period. These were, in fact, questions about ways of making material techniques and reliable commodities into *public* goods. Whether analysed by theory or captured in machines, there was a supposition that somehow the locally-embodied sets of skills characteristic of artisans' practices must be, and could be, rendered more mobile through public spaces. We must thus reflect on how different means of rendering skills and techniques public, accountable and analysable, spectacular and seductive, were crucial for the course of art and industry in the epoch of manufacture.

Sometimes, it seemed very important to restrict and control mobility and publicity. In 1783 Wedgwood published a manifesto to dissuade his errant potters from emigration. Though celebrated as master of a newfangled factory system, his pot production still relied entirely on ingenious manual labour hard to render explicit and harder still to police. Wedgwood described the high-wage paradise summoned into existence in the west Midlands: 'industry and the machine have been the parent of this happy change'. He reckoned that expatriate Britons suffered 'a kind of heart sickness and despair, with an unspeakable longing after their native country'. Historians have sometimes echoed Wedgwood's patriotic geography of skill. They claim that this industrial culture was born British and could only with difficulty flourish elsewhere. Closer attention to Wedgwood's Etrurian vision suggests some problems with this story. The Black Country chemist's eulogy barely concealed his anxiety that skill occasionally travelled too easily. Such masters energetically resisted labour mobility and defended the sites of manufacture against inquisitive visitors and commercial espionage. As William Ashworth points out in his essay in this section, Wedgwood grumbled that enthusiastic excise inspections were really means by which his 'discoveries' could too easily diffuse elsewhere. This was a geography of skill whose locations were sequestered because they could

[16] Neil McKendrick, 'Josiah Wedgwood and factory discipline,' *Historical Journal* 4 (1961): 30-55; Adam Ferguson, *An essay on the history of civil society* (1767; Edinburgh: Edinburgh University Press, 1966), p.182.

leak.[17] But it was also vital to make long-range networks along which lucrative commodities could easily travel and skill be translated. Preoccupied in 1778 with the installation of steam pumps to drain deep Cornish tin mines, James Watt complained to his colleague and rival John Smeaton about the difficulty of finding workers there who could 'put engines together according to plan, as clockmakers do clocks'. The problem was only partly solved when next year Watt and Boulton's firm hired the brilliant Scottish engineer William Murdoch, later celebrated designer of fireworks and gaslights. Simon Werrett explains in his essay here on the themes of theatre and commerce how Murdoch proved master of the hard task of showing his many publics spectacular effects, thence managed to recruit customers and investors for the engine business. Compare the letter about the construction of an engine house, which 'we wish to make more showy than is common,' sent by the Rotterdam entrepreneur J.D.H. van Liender to Boulton and Watt in 1800. The Dutchman gave detailed explanations of the need for show and publicity, thence demanded very detailed plans of how the house and the steam engine should be erected. Here was a notion that such schemes might eliminate need for artisan mobility. 'By your furnishing us with good well executed drawings we shall not want a man from your side to help us in putting th'Engine together'.[18]

There were many reasons why public display, accountability and translation mattered so much to the work of expert artisans and entrepreneurs. Knowledge and skill flows had somehow to be eased, yet also controlled. This remarkable pattern of knowledge movements, public shows and the discipline of skill is therefore the concern here. Werrett's study of the early history of gas lighting explores the full range of public sites of invention, commerce and display that counted in the years around 1800. 'By perseverance, valour, union and magnanimity Europe reposes free, commerce and the arts revive'. Thus read the pyrotechnic display illuminating Boulton's Soho works at the (temporary) end of the Napoleonic Wars in 1802. Such fiery histrionics were soon turned

[17] Josiah Wedgwood, *Address to the workers in the pottery* (1783), Brian Dolan, *Josiah Wedgwood, entrepreneur to the Enlightenment* (London: Harper Collins, 2004), p.345. Compare A.E. Musson and Eric Robinson, *Science and technology in the Industrial Revolution* (Manchester: Manchester University Press, 1969), pp. 216-229; Margaret C. Jacob, *Scientific culture and the making of the industrial West* (Oxford: Oxford University Press, 1997), pp. 176-77, 185.

[18] Richard L. Hills, *James Watt: volume 2. The years of toil, 1775-1785* (Ashbourne: Landmark, 2005), pp.96-105; Jenny Uglow, *The lunar men* (London: Faber, 2002), pp. 284, 291, 397; Jan Verbruggen, *The correspondence of Jan Daniel Huichelbos van Liender with James Watt* (PhD thesis, Universiteit Twente, 2005), p.365. It should be noted that Boulton and Watt would only entertain the idea of providing detailed drawings because Van Liender had previously arranged patent protection for their work in the Netherlands.

into profitable systems of gas lighting in factories and cities alike. But the contrasts between public entertainment and sober industrial enterprise were not the reason for but rather a result of protagonists' accounts of these projects. Showrooms were good places to replicate complex technologies and then to define what would count as a public good. In his essay on the excise and its role in the national economy, Ashworth similarly expands notions of the public and of public accountability's role in economic and industrial enterprise. Consider the task of an excise officer in an English paper-works: the production area had to be mapped, paper bundles checked, samples taken for inspection registered with 'the maker's name, when charged, the quantity, the quality and the value'.[19] Just as somewhat efficient excise systems maintained protective walls behind which nascent English industries developed, so the excise men aimed to make production processes publicly apparent, thus accountable. Ashworth's essay introduces problems typical of eighteenth-century theories of public knowledge, such as the cool accuracy of judgement and the moral reliability of precision. These were in the decades after 1780 urgent matters of administrative and commercial import. He proposes the notion of 'practical objectivity', the forms of public measure adequate for administration of excise yet not so exigent that protest and fiscal collapse would follow.

Both Ashworth's and the following essay by Leonard Rosenband help show how important was the public role of the excise in innovation and extraction of trade knowledge. Rosenband studies the hybrid pattern of flows of knowledge, skill and machinery involved in the development of paper-making machines in the later eighteenth century. This is not a story of effortless overseas diffusion of leading British engineering to less advanced sectors. Rosenband describes enterprises of hybridisation in which techniques from France, the Netherlands and elsewhere were combined in complex ways to produce new sets of skills and machinery. Movements of specifically expert craftsmen and the public accountability of the paper trades mattered decisively to these translations of machinery across the Channel. Finally, Adrian Johns reflects on the world of print, perhaps the most evident symbol and site of public knowledge in the period. Long taken as the chief agent of public knowledge throughout Europe, the press was described by the then pre-eminent apostle of mechanical production, Charles Babbage, as involving 'the union of the intellectual and the mechanical department'. Development of steam presses and of stereotyping was part a history of relations between

[19] William Ashworth, *Customs and excise: trade, production and consumption in England 1640-1845* (Oxford: Oxford University Press, 2003), pp. 248-9.

artisans, proprietors, writers and their publics. Like the other essays presented here, Johns' apt analysis of the vagaries of print culture confirms the judgement of the labour historian Raphael Samuel, that mechanisation was a *process* rather than an *event*, characterised by the combined and uneven development of large ranges of manual skills.[20] Furthermore, mechanical rationalisation and expropriation was crucially dependent on varying notions of how the otherwise seemingly embodied and sequestered labour process could be spelt out, how it could be broken down and better recomposed, thus become some kind of public knowledge.

The essays in this section trouble the assumption that mechanisation went inevitably and easily with publicity and mobility, and they challenge the notion of rapid and thorough expropriation of manual skills. New presses such as those of Charles Stanhope were indeed baptised 'machines'. Processes of stereotyping seemed to offer the possibility of newly standardised and multiplied copies. It was in this sense, precisely, that Babbage could label newspapers nothing but 'advertising machines'.[21] But, as Johns indicates, both conservative and radical practitioners in the print trade insisted that the strenuous maintenance of reliable copying completely depended upon the intensive deployment of manual art. Mechanisation did not dispose of labour but was introduced alongside the intensification of the labour process and the multiplication of labour-intensive tasks.[22] For example, even when press-work was transformed by the introduction of steam-driven cylinder machines, in the nineteenth-century print trades type-setting stayed the prerogative of hand compositors. Similarly, Rosenband explains how in the 1790s the Paris clerk Nicholas-Louis Robert designed a paper-making machine which incorporated artisan agility and skill into a mechanical device. His essay shows how English market leadership in precision engineering was not accompanied by comparable mastery of touch or skill, and Rosenband remains sceptical whether economic and technical development can well be measured by gross calculations of changes in the number and quality of such gadgets.

By rethinking the geography of late eighteenth and early nineteenth century art and industry, another set of stereotypical contrasts comes into

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[20] Raphael Samuel, 'The workshop of the world: steam power and hand technology in mid-Victorian Britain,' *History Workshop Journal* 3 (1977): 6-72, on p.10.

[21] Charles Babbage, *On the economy of machinery and manufacture*, 4th edition (London: Charles Knight, 1835), p. 330, cited in Adrian Johns, 'The identity engine: science, stereotyping and skill in print' in this volume. Compare Louise Henson et al, eds., *Culture and science in the nineteenth-century media* (Aldershot: Ashgate, 2004), part 4: 'Contesting new technologies'.

[22] Maxine Berg, *Age of manufactures*, p.193.

question: that between a rationally managerial, weakly regulated and commercially sober Britain, true home of free-trade manufacture and artful innovation, as opposed to a world *outremanche*, cut off from effective industrial modernity by its pervasive fog of trivially kitsch theatrics, warlike autocracies and airily erudite academies. Staging and setting were crucial, whether in showing philosophical fireworks as forms of gaslight or making ingenious chemical processes in mines and arsenals into sources of expert natural philosophy. French industrial administrators such as the academician Alexandre Vandermonde wrote of metallurgic specialisation and distribution in the 1780s that 'it is the uniformity of manufacture processes, the dexterity acquired by the habit of never doing more than one thing, the employment of tools fitted to each object, which gives that superiority to the tools made in workshops set up in the most suitable places, as in England, over those which private individuals undertake in the different parts of a town, as at Geneva'. But in fact the favoured case of the division of labour, Adam Smith's pin factory, was not of course drawn from immediate British experience but from an article on a provincial French workshop he read in the fifth volume of the *Encyclopédie*, with its famous accompanying gloss by Diderot on the relation between general philosophical laws and humble mechanical contrivance.[23] Similarly, when in the 1760s Wedgwood decided to introduce new lathes to his pottery workshops to accelerate and standardise pattern design, he found he had one very important obstacle in his understanding of machine-tool design. He simply could not read French.[24] We therefore find ourselves in close agreement with recent arguments by historians such as Christine Macleod, who has convincingly argued for a different, rather more pan-European, map of skills, innovations and hardware in the paths to industrialisation taken from the late eighteenth century. An important lesson, then as now, is that technical dissemination and skill transfer was commonly local, site-specific and uneven.[25] It is wrong to exaggerate the persistence of embodied and thus putatively immobile patterns of skill in this period, equally misleading to neglect the crucial roles of mediators and measurers, of travellers and publicists in the forging of new maps of skill.

[23] Liliane Hilaire-Pérez, *Invention technique*, p.151; Adam Smith, *Inquiry into the nature and causes of the wealth of nations*, ed. R.H. Campbell, A.S. Skinner and W.B. Todd (1776; Oxford: Clarendon, 1976), pp. 15-17.

[24] Brian Dolan, *Wedgwood*, pp. 147-148.

[25] Christine MacLeod, 'The European origins of British technological predominance,' L.P. de la Escosura, ed., *Exceptionalism and industrialism: Britain and its European rivals 1688-1815* (Cambridge: Cambridge University Press, 2004), 111-26.

Contemporary analysts and entrepreneurs were much concerned with the urgent question of the place of skill and its possible mobility. Ashworth's examination of debates about the reliability of excise assays reminds us that those industrialists who urged lessening of trade restrictions and campaigned for opening the long-restricted national markets boasted of their leadership in artful skills evident in trades such as textiles, potteries and iron-making. Furthermore, when in the closing years of the eighteenth century public debates raged about the precise combination of ingenious machines and ingenious skill required to make excise judgements reliable, protagonists often debated how techniques such as floating oils or detecting bubbles could well be displaced by exact instruments. The telling contrast that Ashworth finds being made between 'practical correctness' and 'philosophical accuracy', a discrimination of considerable consequence for the polarisation of machine and hand, of reason and art, here appeared in the midst of disputes about how to found public trust. The implication is that the reorganisation of notions of public and publicity accompanied redefinitions of art and industry. They did so especially around practices of machining, measurement and of precision.

These essays all attend in complementary ways to issues of regulation and standardisation of public goods and techniques not because they adhere to an image of a unified, harmonious system of state-controlled economies, but precisely because it was in the local complexities of making and publicising standards and measures that notions such as skill, art and industry were polemically defined. The settings which were to be subjected to routinisation and managerial overhaul, to regulation and the application of putatively standard measures, involved several different forms of organisation, from family groupings and communal enterprises through large-scale mills and state-run factories. Whether in the print-trades described by Johns and the paper-trades charted by Rosenband, or in the ubiquitous 'common economy' which both challenged and in many ways escaped the excise system, as Ashworth shows here, uniformity of measures and goods was proffered as an object never quite realisable and in some ways undesirable. This was why engineers would rightly challenge the relevance of model production systems: one millwright grumbled about 'gentlemen who have gone through the nation, who have exhibited small models of water wheels and steam engines…there is no judging of the merit of any design unless the model is as large as the machine it represents is intended to be'.[26] Models mattered

[26] John Sutcliffe, *Treatise on canals and reservoirs* (Rochdale, 1816), in Terry Reynolds, *Stronger than a hundred men: a history of the vertical water wheel* (Baltimore: Johns Hopkins University Press, 1983), p. 250.

because they were both descriptive proxies for and normative recommendations about virtuous industry. Such models were the stock-in-trade of innovative schemes in papermaking, brewing or gaslight. Scenes of production and distribution were thus to be overhauled in the name of transparency, accountability and philosophical analysis, and such plans often concerned the state. The work of John Brewer reminds us of the efficiency, extent and calculative agency of the British excise, with its 'slips of paper rather than shot and cannon, slide-rules rather than blades of swords'. One implication of this picture of the fiscal-military state is that public analysis of production both guaranteed and also depended on exercise of legal power and manufacturing discipline. [27]

Such forms of inspection were never merely passive enterprises of observation that left untouched the social and technical systems under surveillance. To extract this kind of knowledge was also, precisely, to change the relations and the geography of production and of the commodities produced. In his 1770s surveys of the advantage of Dutch over French paperworks, Desmarest urged 'the creation of a workshop where all the processes and machines would be in operation and which would be open to the observation and research of those who would like to inform themselves. Such a workshop, designed according to a rational plan, would show the order and connection of the operations, their sequence and progression'. Such plans were often treated with scepticism; but they were as often seen as prerequisites for the enlightened reordering of production and the expropriation of skill.[28] In the Swedish forests, for example, traditional and secluded systems of charcoal burning provided most of the fuel for the economically vital iron industry. The technology historian Svante Lindqvist has contrasted two Swedish attempts to test methods of charcoal burning, one in an Uppsala university thesis of 1746, the other an experimental programme run for the Swedish Ironmasters' Association in 1811. The scholar failed to enter, control and thus know the arboreal world of the burners. But with the backing of the powerful ironmasters, officials decades later could turn charcoal piles into geometrically tractable objects and use newfangled French calorimetry to assay heat output. All this hinged on reorganising the space and social relations of the charcoal economy. Such reformist managerial enterprises were not always successful. When the splendid Prussian mining corps sought in the early 1800s rationally to displace traditional charcoal systems by novel

[27] John Brewer, 'The eighteenth-century British state,' Lawrence Stone, ed., *An imperial state at war: Britain from 1689 to 1815* (London: Routledge, 1994), p.60.
[28] Desmarest, 'Second mémoire,' in Gillespie, *Science and polity in France*, p.452.

experimental coke furnaces in the iron industry, their initiatives failed and they were forced to rely instead on customary charcoal systems and then on smuggling skilled British technicians into the Kingdom.[29]

Espionage and smuggling, adulteration and forgery were all good indications of what could travel and what could not.[30] Commercial frauds and dodgy copies were ways of exploiting commodities' public reputation without having exactly to learn original recipes. Somehow or other, values were to be made and broken in the public realm of the market and the courts. This was where the identity of print and property rights in copies, as Johns points out, were both resources and puzzles. Ashworth stresses that problems of adulteration of goods were as much challenges to the excise as to common welfare. And these reputations were also established through complex systems of advertising and of invigilation. As has been rightly urged by Maxine Berg, much invention in this period involved imitative import substitution: so public knowledge of, and attitudes to, mobile commodities was crucial.[31] Similar juridical and political-economic fights about the development and ownership of gas technologies, discussed here in Werrett's essay, also testify to the importance of this new geography of skills and of repute. Thus in the contest between Murdoch and Winsor over the rights to the invention of gaslight, ingenious combinations were forged between the approval of the learned societies and their organs of publicity, and the demonstration of public utility and economic profit. This was certainly not a moment when market values and philosophical truths were utterly sundered. But it was, significantly, a period when many protagonists began to urge a fundamental distinction between the values of the artful operatives and those of the gentlemen of science. However much he admired finger-end knowledge, Nasmyth trusted automatic machinery and stern discipline rather more. His production utopia was, so he recalled, stocked with 'self-acting machine tools, by which the untrustworthy efforts of hand-labour might be avoided. The machines never got drunk; their hands never shook from excess; they were never absent from work; they did not strike for wages; they were unfailing in their accuracy

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[29] Svante Lindqvist, 'Labs in the woods: the quantification of technology during the late Enlightenment,' in Tore Frangsmyr, J.L. Heilbron and Robin E. Rider, eds., *The quantifying spirit in the eighteenth century* (Berkeley: University of California Press, 1990), pp. 291-314, on pp. 301-306, 313; Eric Dorn Brose, *The politics of technological change in Prussia 1809-1848* (Princeton: Princeton University Press, 1993), pp. 149-55.

[30] John Harris, *Industrial espionage and technology transfer: Britain and France in the eighteenth century* (Aldershot: Ashgate, 1998).

[31] Maxine Berg, 'In pursuit of luxury: global history and British consumer goods in the eighteenth century,' *Past and Present* 182 (2004): 87-141.

and regularity, while producing the most delicate or ponderous portions of mechanical structures.'[32] This final group of essays sets out to analyse and explain how the intimately tense relationships between capital enterprises and knowledge systems of the decades round 1800 managed to produce such a world, in which head and hand were put so strikingly at odds.

[32] Samuel Smiles, *James Nasmyth*, pp.201-2. For comparable fantasies of such production utopias in early industrialisation, see Thomas Markus, *Buildings and power: freedom and control in the origin of modern building types* (London: Routledge, 1993), pp. 286-90.

The sites of philosophical fireworks in late eighteenth-century London: 1. Lyceum Theatre, Exeter 'Change, site of Diller and Winsor's shows; 2. Royal Society, Somerset House; 3. Carlton House, residence of the Prince of Wales; 4. Royalty Theatre, Well Street, site of Diller's last London shows; 5. Green Park, site of the 'Grand Whim'; 6. Marylebone Gardens; 7. Ranelagh Gardens, location of early commercial fireworks; 8. No. 97 Pall Mall, residence of F.W. Winsor, and the site of the first gas street-lights; 9. Parliament, location of the debates over Winsor's gas-light bill. John Fairburn, 'London and Westminster, 1797' (London, 1797), *Maps.d17.G.6.* By permission of the Syndics of Cambridge University Library.

ILLUSTRATION 33

From the grand whim to the gasworks: 'philosophical fireworks' in Georgian England

Simon Werrett

Hesper of Science! Philosophic light!
Like NEWTON sent to illumine Britain's night,
To pure caloric change AUGUSTA's smoke,
Her soot to aether, and her coal to coke…
And soon the fire-works by thy genius plann'd,
Light every nook and corner of the land;
Beacons and telegraphs like Pharos blaze,
And Britain's shores illumine with patent rays.[1]

The history of gas-lighting illustrates a common distinction drawn in studies of invention, between suspicious theatricality and admirable industry. Wolfgang Schivelbusch, in what remains the best account of the 'industrialisation of light in the nineteenth century' contrasted the lavish illuminations of the *ancien regime* court in France with industrial gas-lighting in Britain. While the court lit up buildings with thousands of coloured lanterns in festive displays of conspicuous consumption, English households and factories of the industrial revolution employed light, says Schivelbusch, 'in a rational and economic way, not as a vehicle for conspicuous consumption'. Gas-lighting arose in this industrial context as a cheaper, safer and more brilliant method of lighting, which extended the working day and hence the profits of industry. Until 1808, Schivelbusch goes on, 'gaslight was used exclusively for lighting factories'.[2] British reason, economy, and manufactures, oppose French court, theatre and extravagance.

A similar contrast is made regarding the protagonists of early gas-lighting. John Griffiths, in his biography of William Murdoch, the British claimant to the invention of gas-lighting, notes:

[1] *An heroic epistle to Mr. Winsor, the patentee of the hydro-carbonic gas lights and founder of the national light and heat company* (London, 1808).
[2] Wolfgang Schivelbusch, *Disenchanted night: the industrialization of light in the nineteenth century*, trans. Angela Davies (Berkeley, CA: University of California Press, 1995), pp. 6-9, 19-20. Schivelbusch deals with theatre, but only to the degree that it was affected by lighting developments, ibid., pp. 191-221.

The different attitudes and priorities of France and England... are graphically illustrated by the very different applications made by the French and British discoverers of practical gas-lighting; the one attracted by the show and glamour of its social and public uses... the other drawn to means of enhancing the efficiency and profitability of industry.[3]

Murdoch is typically portrayed as an industrial genius who discovered gas-lighting alone in an isolated cottage in Cornwall in 1792, before applying it to the illumination of Manchester cotton mills in 1805, beginning the trend of industrial gas-lighting.[4]

In contrast, the Moravian Frederick Albert Winsor, who applied the gas-stoves of Parisian Philip Lebon to London street-lighting around 1804, is presented as a showman and swindler. Winsor appears as a 'half-visionary, half conman' who popularised, but did not invent gaslighting, that honour being left to Murdoch.[5] As a student of Murdoch's, Samuel Clegg, wrote in 1841, Winsor,

was not cast in the same mould as Mr. Murdoch... One was a philosophical investigator – the other an impetuous schemer... To one belongs the honour of being an inventor, whilst the other is as fully entitled to the... honour of being the successful promulgator of the new science.[6]

Clegg neatly separated the ingenious inventor from the practical showman, a view repeated to this day.[7] Even Schivelbusch writes that Winsor was 'not a serious capitalist entrepreneur'.[8]

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[3] John Griffiths, *The third man, the life and times of William Murdoch, 1754-1839, the inventor of gas lighting* (London: Andre Deutsch, 1992), p. 261.

[4] On the image of the isolated genius, see Patricia Fara, *Newton: the making of genius* (London: Macmillan, 2002); Simon Schaffer, 'Genius in romantic natural philosophy,' Andrew Cunningham and Nicholas Jardine, eds., *Romanticism and the sciences* (Cambridge: Cambridge University Press, 1990), pp. 82-98.

[5] T. S. Peckston, *The theory and practice of gas-lighting in which is exhibited an historical sketch of the rise and progress of the science* (London, 1819), pp. 94-100; William Matthews*, An historical sketch of the origin, progress, and present state of gas-lighting* (London, 1827); Charles Hunt, *A history of the introduction of gas lighting* (London: Walter King, 1907); Dean Chandler and A. Douglas Lacey, *The rise of the gas industry in Britain* (London: British Gas Council, 1949); Sir Arthur Elton, 'Gas for light and heat,' Charles Singer, E. J. Holyard, A. R. Hall, and Trevor I. Williams, eds.,*A history of technology*, 8 vols. (Oxford: Clarendon Press, 1954-84), vol. 4, *The industrial revolution, 1750-1850* (Oxford: Clarendon Press, 1958), pp. 258-276; M. E. Falkus, 'The early development of the British gas industry, 1790-1815,' *The economic history review* 35 (1982):217-234; An account favouring Winsor is Stirling Everard, *The history of the gas light and coke company, 1812-1949* (London: Ernest Benn, 1949), pp. 17-26.

[6] Samuel Clegg jr*, A practical treatise on the manufacture and distribution of coal-gas* (London, 1841), quoted in Dean Chandler and A. Lacey, *Rise of the gas industry*, p. 46.

[7] Chandler noted of Winsor, 'The salt of prudence... was very conspicuously absent in the make-up of this enthusiast' while Murdoch was an 'outstanding engineer' full of 'ingenuity and resourcefulness', Dean Chandler and A. Lacey, *Rise of the gas industry*, pp. 21-3.

[8] Wolfgang Schivelbusch, *Disenchanted night*, p. 26.

A careful analysis of the settings of early gas-lighting reveals the problems of making sharp contrasts between court and manufactures, France and England, and the 'industrious inventor' and 'showman projector'. This essay seeks to break down such contrasts, though it suggests their historiographical existence is comprehensible when the spaces through which gas-lighting passed are examined. Rather than essentialise or localise these contrasts in individuals or national 'characters', it is better to consider them as fluid categories linked, but not bound to, the sites in which gas-lighting moved. At the turn of the nineteenth century, courtly and industrial settings in both Britain and France were inextricably connected, or rather had yet to be resolved into distinctive forms. The people who busied themselves with gas-lighting circulated through these sites, and adjusted their discussion and presentation of gas-lighting according to where they were.[9]

Instead of dismissing 'showmanship' as a folly to the progress of gas-lighting, this essay proposes that the *theatre* was in fact a key site from which gas-lighting sprang. Doubtless the development of gas-lighting drew on many sources, but here the focus will be on one such source, the late eighteenth-century theatre of fireworks and illuminations, and specifically a range of novel venues where pyrotechnics were performed – the showrooms, pleasure gardens and theatres of both Britain and France.[10]

In the late eighteenth century, such venues sprang up as homes for a new form of fireworks, which blended the skills of natural philosophers, pyrotechnicians, theatre owners and entrepreneurs. Theatres became the location of a bustling culture of ingenious interactions, exemplified in shows of a Dutch physicist named Diller. Diller used the recently discovered inflammable air to make spectacular displays of coloured flames which soon became a theatrical sensation. Following the career of these 'philosophical fireworks' through the theatres of Paris and London reveals the wealth of interaction between science, manufactures, court and theatre. It also reveals a path to gas-lighting,

9 On spatial accounts of the history of science and technology, see David Livingstone, *Putting Science in its place: geographies of scientific knowledge* (Chicago: University of Chicago Press, 2003); Crosbie Smith and Jon Agar, eds., *Making space for science: territorial themes in the shaping of knowledge* (Basingstoke: Macmillan, 1998).

10 On the history of eighteenth-century fireworks and illuminations, see Alan St. Hill Brock, *A history of fireworks* (London: George G. Harrap, 1949); Arthur Lotz, *Das Feuerwerk, seine Geschichte und Bibliographie* (Leipzig: Verlag Karl W. Hiersemann, 1941); Kevin Salatino, *Incendiary art: the representation of fireworks in early modern Europe* (Los Angeles: Getty Research Institute, 1997); on showrooms and pleasure gardens, Richard D. Altick, *The shows of London* (Cambridge, Mass.: Belknap Press, 1978); Robert M. Isherwood, *Farce and fantasy, popular entertainment in eighteenth-Century Paris* (Oxford: Oxford University Press, 1986); Gilles-Antoine Langlois, *Folies, tivolis, et attractions – les premiers parcs de loisirs parisiens* (Paris: Délégation à l'Action Artistique de la ville de Paris, 1991).

since the first developers of gas occupied the same venues as Diller and his colleagues and promoted their projects as part of the flourishing trade in novel pyrotechnics. Although men like Lebon, Winsor and Murdoch gave much weight to the domestic and industrial uses of gas lights, this was more a difference in emphasis than in kind. Until about 1805, gas-lighting was comfortably fixed in a popular theatrical milieu of philosophical fireworks taking in both London and Paris.

That year witnessed the beginnings of Murdoch's schemes to light the cotton mills, and Winsor's efforts to begin a national company devoted to gas street-lighting. Both men had engaged in the theatrical culture of philosophical fireworks, and now both took gas to new venues – Murdoch to the manufactories of Northern England, and Winsor to the fashionable locations and elite institutions of London. Both men sought to make a profit from gas-lighting, leading to a priority dispute over the new technology. The dispute took place in new venues, in establishment spaces, such as the Houses of Parliament and Inns of Court. The change of venue dramatically altered the way gas-lighting was to be understood, since establishment sites warranted a different kind of talk about gas to the theatres, focusing on scientific practicalities and the legal and economic proprieties of patents and monopolies. As gas projectors sought to profit from their schemes, so they needed to proscribe their activities as distinctive, original and distant from the theatrical milieu from which they sprang. Crucially in this milieu, both Winsor and Murdoch attacked their opponent by trying to ally them to the theatrical world of Diller's fireworks. Priority could be denied if gas was just an extension of Diller's theatrical flames. A change of *place* thus helped consolidate an image of gas-lighting as distinct from theatrical pyrotechny.

The definition of the 'inventor' was polarised in a similar manner, separating out the foreign showman from the sensible British inventor. Once Murdoch won the debate, this distinction would be institutionalised in a wealth of historical accounts which, following Murdoch's priority claims, rooted gas-lighting firmly in British industrial ingenuity, and tied Winsor to theatricality, speculative projecting and folly. The essay thus demonstrates how attributions and meanings of entities like 'theatre', 'industry' and 'invention' were contingent upon, and emergent from, the different sites and circumstances where they were invoked. Once established, their distinctions served historians as causal explanations for the fate and nature of different gas-lighting schemes.

Philosophical fireworks

This history of gas-lighting begins with an overview of the pyrotechnic culture of London and Paris in the second half of the eighteenth century. A myriad of shows blending science, commerce and fireworks delighted audiences in London and Paris during the second half of the eighteenth century. This culture, which will here be termed 'philosophical fireworks,' owed its origins to changes in royal pyrotechny, though it was far from being divorced from the tradition of royal spectacle. The French and British courts long celebrated themselves with fireworks, usually performed by expert families imported from Italy and the Germanies. But by the mid-eighteenth century, grand royal fireworks were proving troublesome and expensive. Accidents and high costs led to criticisms in the public sphere, with journalists and letter-writers condemning the extravagance. In London, for example, a temple erected in Green Park for the Peace of Aix-la-Chapelle in 1749 burnt down causing much indignation.[11] It was the 'Grand Whim for Posterity to Laugh At' according to a popular print, a 'fanatick idle shew' (Ill. 34). As a result, royal fireworks underwent a transformation in subsequent decades, scaled down and given smaller budgets more fitting with public sentiment and government purses. From the late 1760s, grand illuminations of gardens, public and commercial buildings with candles and coloured lanterns were increasingly the preferred, and most economic, mode of celebrating royal occasion.[12]

Just as the court economised, so constricted budgets for fireworks led royal pyrotechnists, or 'artificers' as they were known, to seek alternative revenues. Economic application, a principle dear to gas-lighting promoters, was already a part of pyrotechnic practice long before the first gas-lights were turned on. In Paris, enterprising royal artificers began opening pleasure gardens for fireworks in the 1760s.[13] London's artificers set up shops and performed displays for cash at Mulberry Gardens, Marylebone, and Ranelagh.[14] As fireworks became a market, so competition drove searches for distinctive novelties, a process also driven by the desire to substitute local innovations for foreign expertise. To create novel fireworks, French and British artificers turned to fashionable natural philosophy.[15]

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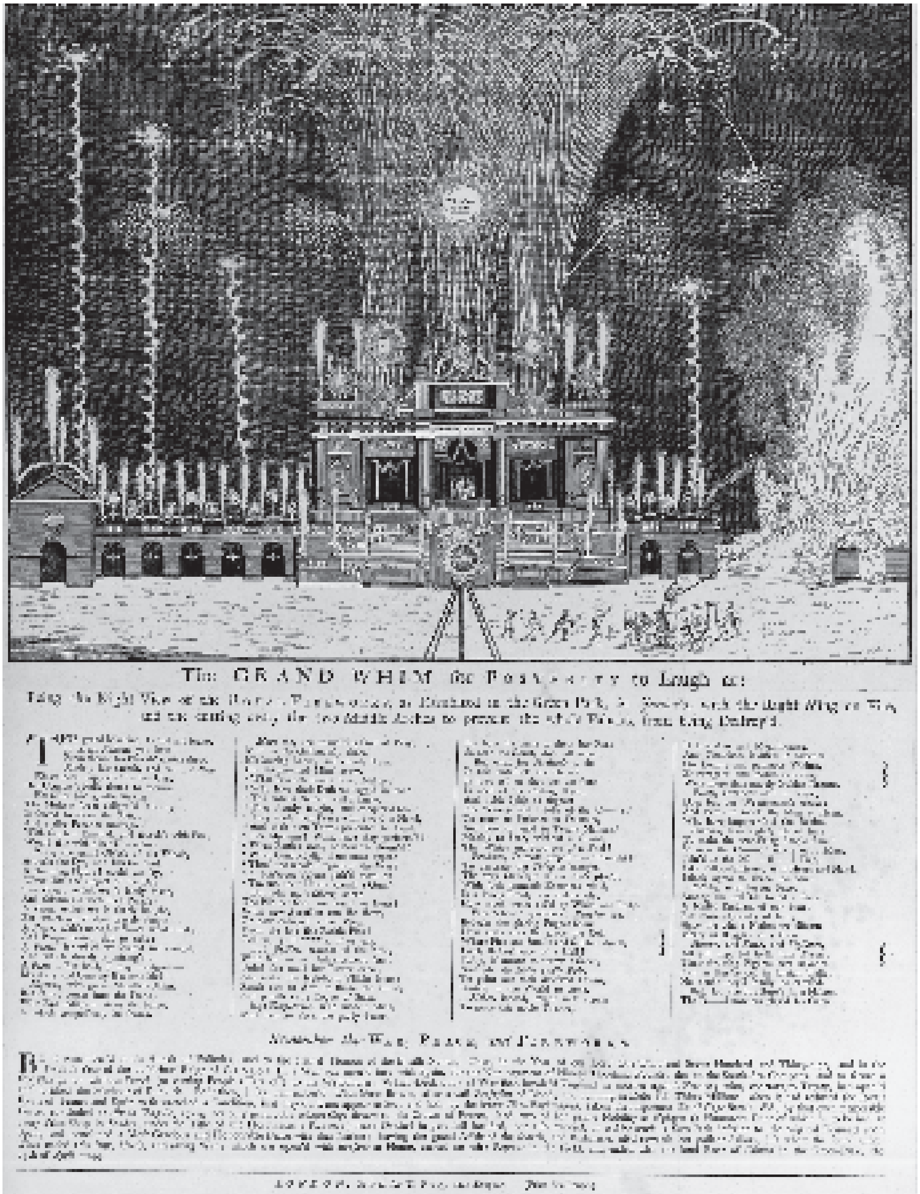
[11] See Anon, 'On the fireworks,' *Gentleman's Magazine*, May 1749, pp. 204-205; letter from 'Anti-pyrobolos', *Gentleman's Magazine*, May 1749, pp. 220-1; *The Green-Park folly, or the fireworks blown up: a satire* (London, 1749).

[12] For a selection of Georgian illuminations, see *Times*, 19th January 1788, p. 3; *Universal Magazine*, April 1789, pp. 218-220; *Times*, 19th January 1791, p. 3; *Times*, 19th January 1792, p. 3; *Times*, 5th June 1792, p. 3.

[13] Alain-Charles Gruber, 'Les 'Vauxhalls' Parisiens au XVIII^{e} siècle,' *Bulletin de la Société de l'Histoire de l'Art français, Année 1971* (Paris: F. de Noble, 1972), pp. 125-143.

[14] On commercial fireworks, see James Granville Southworth, *Vauxhall Gardens: a chapter in the social history of England* (New York: Columbia University Press, 1941), pp. 84-105; Warwick Wroth, *The London pleasure gardens of the eighteenth century* (London, New York: Macmillan, 1896), passim.

[15] On the importance of import substitution for invention in the eighteenth century, see Ashworth, this volume. Superceding foreign pyrotechny was the stated aim of several fireworks manuals of the



Ill. 34. *The GRAND WHIM for POSTERITY to laugh at: being the night view of the ROYAL FIREWORKS, as exhibited in the Green Park, St. James, with the right wing on fire* (London, 1749) (detail). Copyright the Trustees of The British Museum.

The 1760s and 70s witnessed an abundance of new kinds of fireworks as artificers blended together science and pyrotechny. Philosophers in turn used fireworks to dramatise lessons on Nature. Performers imitated Nature with fireworks, and fireworks with natural phenomena. Fireworks at the Cirque Royale in Paris depicted solar eclipses and the transit of Venus, while French royal artificer Petrone Ruggieri turned to Antoine Lavoisier to devise coloured flames for shows in his Paris pleasure garden.[16] Women artificers flourished in this environment. One Madamoiselle Saint-André tempted visitors such as the Abbé Nollet and Jacques Vaucanson with fireworks in her Paris atelier.[17] Performances were intimately entangled with fashionable science. As Saint-André's advertisements read, 'Her principles are taken from the sciences from which pyrotechny naturally derives, such as physics, mechanics, and geometry… the sole means leading to the success which connoisseurs admire in the work of this lady'.[18] An approbation from the Paris Academy of Sciences hung on the door of Saint-André's shop, lending authority to her wares.

Savants contributed much to the new fireworks. Books of rational recreations in the 1790s explained how to imitate fireworks using electricity, lenses and mirrors, while Lavoisier advised the police on the practicability of new methods for igniting illuminations at Versailles.[19] The boundary between royal and commercial spectacle remained fluid. French and British royalty attended displays in commercial pleasure gardens, while fireworks manufacturers displayed royal

period. See e.g. Robert Jones, *A new treatise on artificial fireworks* (London, 1765); Jean Charles Perrinet d'Orval, *Essay sur les feux d'artifice pour le spectacle et pour la guerre* (Paris, 1745).

16 *Journal de Paris*, 12th July 1778, p.772; *Journal de Paris*, 2nd August 1778, p.856; the Cirque Royale fireworks were ignited with 'courantins' – not electric sparks, but rockets attached to cords. Even so, Pilâtre de Rozier exploded gunpowder with electric sparks in his physics lectures, see Robert Darnton, *Mesmerism and the end of the Enlightenment in France* (Cambridge, Mass.: Harvard University Press, 1968), p. 178; On the Ruggieri's links with Lavoisier, see Simon Werrett, 'Explosive affinities: pyrotechnist's knowledge in early modern Europe,' in *Knowledge and its making in early modern Europe*, Pamela H. Smith and Benjamin Schmidt, eds. (forthcoming).

17 'Pyrotechnie,' *Avant-Coureur*, 22nd October 1764, pp. 674-5; 'Pirotechnie,' *Avant-Coureur*, 23rd December 1765, pp. 800-801; *Avant-Coureur*, 7th September 1767, pp. 574-5; 'Spectacle Pyrique de Mademoiselle de S. André,' *Avant-Coureur*, 28th September 1767, pp. 620-621.

18 'Pirotechnie,' *Avant-Coureur*, 2nd December 1765, pp.750-51.

19 Edme-Gilles Guyot, *Nouvelles récréations physiques et mathématiques, contenant ce qui a été imaginé de plus curieux dans ce genre et qui se découvre journellement* (Paris, 1799), describes how to make fireworks 'by the sole interposition of light and shadow,' pp. 269-285; as does Jacques Lacombe, *Dictionnaire encyclopedique des amusemens des sciences* (Paris, 1792) pp. 836-838; Antoine Lavoisier, 'Rapport sur une manière d'allumer simultanément un grand nombre de lampions, du 4 février 1772,' *Oeuvres de Lavoisier*, ed. Edouard Grimaux, 6 vols. (Paris, 1862-93), Vol. 4 (Paris, 1868), pp. 106-8; 'Détail des illuminations faites… 19 Mai 1770,' *Mercure de France*, July 1770, pp.191-199; Claude-Fortuné Ruggieri, *Précis historique sur les fêtes, les spectacles et les réjouissances publiques* (Paris, 1830), pp. 300-2.

credentials on advertisements, with pictures of the Green Park temple adorning several British artificers' cards.[20]

A distinctive concern of all these displays centred on rendering fireworks 'polite' – cleaner, safer and more economical, devoid of the inflammatory risks and sooty by-products of traditional fireworks which might upset the sentiments of the Vauxhall-going public. They should be 'brilliant and inoffensive' as one reviewer put it.[21] Gaslighting schemes would often repeat this claim in the early nineteenth century, but it followed directly from the social niceties of philosophical fireworks, as pyrotechny shifted to popular markets and venues. Thus a Mr. Flockton displayed fireworks 'without Noise, Smell, or Smoke', probably *vues d'optiques*, in London, while in Paris, Saint-André sold the first 'indoor fireworks', designed to amuse friends visiting one's apartment. Tiny cartridges avoided the mess of smoky pyrotechnics, and just in case, Saint-André gave instructions, saving 'the embarrassment which these executions ordinarily cause'.[22]

The most successful of the new 'inoffensive' fireworks appeared in the late 1780s. 'Diller's Philosophical Fireworks' used the recently discovered inflammable air to make dramatic imitations of real, but impolite, fireworks. Diller's shows became something of a craze over the next decade, not as widespread as ballooning, automata, or mesmerism, but a sensation nevertheless.[23] Inflammable air fireworks travelled far, became famous, entered chemistry and natural philosophy textbooks, and were reproduced by a variety of showmen and instrument-makers. Their career makes evident the broad presence of spectacular displays of gas-lighting in Britain and France in the 1780s, predating the use of gas for lighting manufactories and streets. They are exemplary of the theatrical context from which the new gas-lighting emerged.

Charles Diller styled himself a 'physicien-mechanicien' and was probably a student of Jean-Nicolas-Sébastien Allamand, Leiden professor and publisher of Willem 's Gravesande's works. In the 1780s, Diller worked in the Hague, promoting balloon ascents and supplying electrical demonstration instruments and machines for imitating fireworks with inflammable air to the physical

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[20] See e.g. the trade cards of Benjamin Clitherow and Samuel Clanfield, Sarah Banks collection, British Museum, ref. 62.6 (Clitherow); Heal Collection of trade cards and shop bills, British Museum, ref. 62.4 (Clanfield).

[21] *The Gazetteer*, 21st May 1788, in Rev. Daniel Lysons, *Collectanea, or, a collection of advertisements and paragraphs from the newspapers, relating to various subjects*, unpublished collection of cuttings from 1661-1840, 5 vols, British Library, C103.K.11, vol. 4, part I, p.31.

[22] *Mr. Flockton's theatre. At the* [White Lyen Highgate] *in this town. This present evening, will be exhibited his grand exhibition, in the same manner as performed before the royal family and most of the nobility in the kingdom* (London, c.1780); *Avant-Coureur*, 2nd December 1765, p. 751.

[23] On science as a craze, see Robert Darnton, *Mesmerism*, p. 27.

cabinet of stadholder William V.[24] By 1787 he was in Paris, where the 'philosophical fireworks' were first shown at the Panthéon in late June.[25]

Performances hinged on imitating colourful pyrotechnics with gas. Diller compressed a series of bladders, filled with several kinds of inflammable air from reservoirs, conveying the air through valved copper pipes. These terminated with tubes arranged in various shapes and punctuated with holes. By manipulating the bladders, Diller altered the combination of airs in the tubes, which, when lit with a taper, created coloured flames in the shape of suns, stars and geometrical figures. Inflammable air was used because, like Saint-André's indoor fireworks, it was 'inoffensive' – 'The air thus conveyed… ascends without inflammation to the mouths of the tubes… where it immediately inflames, without smell, smoke, or detonation, producing much… beyond the possibility of description'.[26]

It was a show equally of natural philosophy and pyrotechny. Like Saint-André, Diller sought the approbation of the Paris Academy, and on 17th July, an academic commission including Lavoisier, Berthollet, and Fourcroy witnessed Diller's performance.[27] Their report praised Diller in glowing terms, perhaps for making a fantastic spectacle of the chemical philosophy and its newly-discovered airs.[28] A royal performance for Louis XVI followed, for which Diller was awarded an annual pension.[29] Soon the show was being imitated in the Paris pleasure gardens. By April 1788, Diller had taken his fireworks to the Lyceum theatre in London, where he taught his techniques to several students.[30] From there the philosophical fireworks spread far and wide, to the

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[24] Diller's career is noticed in Peter de Clercq, 'Science at court: the eighteenth-century cabinet of scientific instruments and models of the Dutch stadtholders,' *Annals of science* 45 (1988):113-152, on pp. 124-5, 138; a list of Dutch physics cabinets including instruments by Diller may be found in Maria Rooseboom, *Bijdrage tot de geschiedenis der instrumentmakerskunst in de Noordelijke Nederlanden tot omstreeks 1840* (Leiden: Rijksmuseum voor de Geschiedenis der Naturwetenschappen, 1950), p. 58; J. Smit, 'Achttiende eeuwse luchtvaartproeven in Den Haag,' *Jaarboek Die Haghe*, 1914-15, pp. 338-353.

[25] *Journal de Paris*, June 28th 1787, pp. 788-789.

[26] 'Philosophical Fire,' *The Scots Magazine*, April 1788, p. 164; The most detailed account of Diller's performances is *Mémoire sur les feux d'air inflammable par M. Diller. Extrait des Registres de l'Académie Royale des Sciences, du 4 Juillet 1787* (Paris, 1787).

[27] The commission consisted of Antoine Lavoisier, Jean-Baptiste le Roy, Mathurin-Jaques Brisson, Gaspard Monge, Claude-Louis Berthollet and Antoine-François de Fourcroy. See 'Mémoire sur les feux d'air inflammable,' p. 1.

[28] Compare the Academy's reactions to the dowser Barthelemy Bléton and Franz Anton Mesmer's cures, see Michael R. Lynn, 'Divining the Enlightenment: public opinion and popular science in old regime France,' *Isis* 22 (2001): 34-54; Darnton, *Mesmerism*.

[29] *Journal encyclopédique ou universel*, August 1787, vol. 5, part 3, p.153.

[30] The *Jardin Ruggieri* displayed fireworks with inflammable air, circa 1787, turning to Lavoisier to assure the police of their safety. Antoine Lavoisier, 'Rapport sur les procédés d'artifice proposé par

Royalty Theatre, then to Birmingham, Oxford, Cambridge, even arriving in New York and Philadelphia by the turn of the century.[31] Audiences continued to see the fireworks as a spectacle of science. A British writer called it 'a new art… an epoch in natural philosophy,' a line soon picked up in Diller's advertisements, 'It ought to be known that Mr. Diller, in attaining this exclusive perfection, trod the path, which Boyle, and other great Philosophers… first traced out'.[32]

Diller's fireworks were also incorporated into experimental repertoires. Following the Academy's review in Paris, the physics demonstrator François Bienvenu and the instrument-making Dumotiez brothers reproduced Diller's fires and sold apparatus for imitating his shows, while in London, George Adams used Diller's techniques in philosophical lectures to demonstrate the properties of hydrogen.[33] By 1804, inflammable air fireworks had even reached chemistry textbooks, that of Spanish chemists José Maria de S. Christobal and Josep Garriga i Buach including an illustration of the apparatus (Ill. 35).[34]

Shows of gas-lighting were thus becoming common in both Britain and France well before Murdoch and Winsor's commercial applications. Performances even made reference to commercial and utilitarian potential. Promotions for Diller's shows claimed his lights could be used for 'Light-houses, to the Splendour and Brilliancy of which the Rays of 100 Patent Lamps, collected in the same focus would be much inferior,' while Bienvenu's imitations of Diller's apparatus were made expressly for use as lamps.[35] Promoters also continued to stress the 'inoffensiveness' of fireworks made with inflammable air, promoting them as 'destitute of smell or smoke, yet inflammable in the closest apartment, and incapable of detonation by coming into contact with atmospheric

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M. Ruggieri,' *Oeuvres de Lavoisier*, ed. Edouard Grimaux, 6 vols. (Paris, 1862-93), vol. 4 (Paris, 1868), pp. 417-8; *Mr. Diller's grand exhibition of new-invented philosophical fireworks from inflammable air, exhibited… at the Lyceum, near Exeter 'change, Strand* (London, 1787).

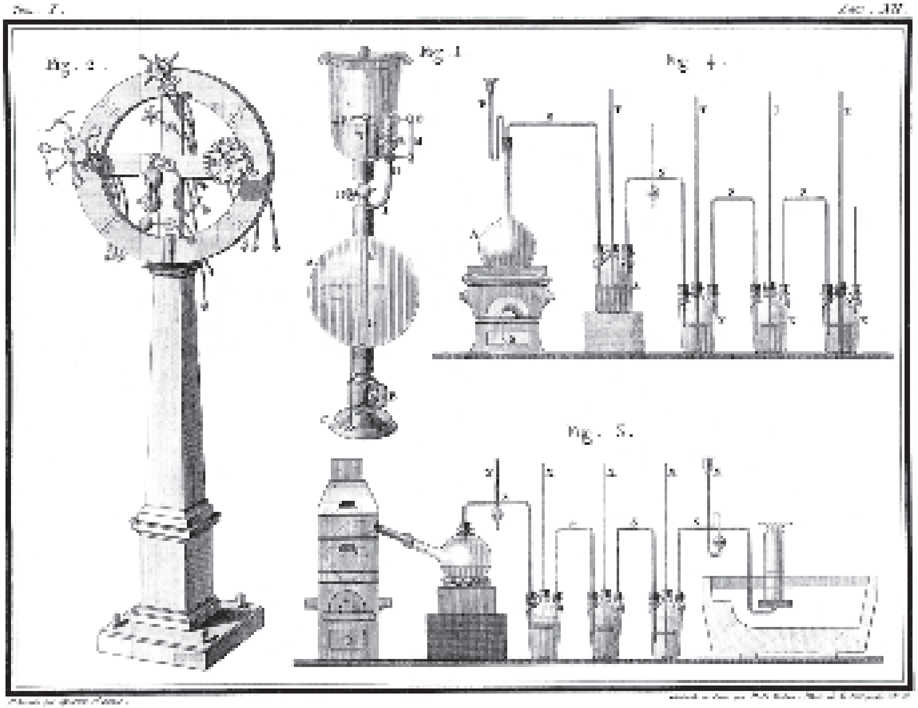
[31] See e.g. Daniel Lysons, *Collectanea*, vol. 4, part I, p.63; John Alfred Langford, *A century of Birmingham life*, 2 vols. (Birmingham: W.G. Moore,1870), I, p.399; *Times*, 4th June 1789, p. 1; Alan Brock, *History of fireworks*, pp. 60-61*; Saturday Evening Post* (Philadelphia) 1st January 1825, p.2; 'Mr. Cartwright's musical glasses, and pyrotechnics,' *The Euterpeiad; or, Musical Intelligencer, and Ladies Gazette* (Boston) 17th March 1821, p. 203.

[32] Anon., 'Philosophical Fire,' *The Scots Magazine*, April 1788, p. 164; *Times*, 5th June 1788, p.1.

[33] On Bienvenu, 'Extrait d'un Rapport de l'Académie Royale des Sciences du 7 Juin 1788,' *Journal de Paris*, 4th July 1788, p. 814; on the Dumotiez, *The analytical review, or history of literature, domestic and foreign*, September to December 1788, p. 504; George Adams, *Lectures on natural and experimental philosophy*, 5 vols. (London, 1794), I, pp. 495-6.

[34] José María San Cristóbal and Josep Garriga i Buach, *Curso de química general aplicada a las artes*, 2 vols. (Paris, 1804-1805), I, p. 235.

[35] Advertisement quoted in John Langford, *A century of Birmingham life*, I, p. 399; See also 'Mémoire sur les feux d'air inflammable,' p. 2; On Bienvenu, 'Extrait d'un Rapport,' p. 814.



Ill. 35. Machine for producing fireworks from inflammable air, from José María San Cristóbal and Josep Garriga i Buach, *Curso de química general aplicada a las artes*, 2 vols. (Paris, 1804-1805), Vol. 1, p. 235. Courtesy of the Bibliothèque Nationale de France.

air'.[36] There was little distance between these theatrical shows and the first gas-lighting schemes, which would make identical announcements.

Gas-lighting

Certainly, the immense popularity of philosophical fireworks was not lost on the better-known developers of gas-lighting, men like Philip Lebon, Frederick Winsor and even William Murdoch. It is easy to see their work emerging from and engaging in these spectacular milieux, pushing the values of 'brilliant and inoffensive' light into new arenas, but rarely straying far from the showrooms of the city theatres.

Theatricality was an essential resource for gas-lighting promoters. Take, for example, the career of Philip Lebon, a graduate of the Ecole des Ponts et

[36] Anon., 'Philosophical fire,' p. 164.

Chausées, who presented a 'new means of employing combustibles… for heat and light,' which he named the Thermolamp, in 1801.[37] Lebon's Thermolamps changed the priority of philosophical fireworks, but not the ingredients. Consisting of a retort, which burnt wood to produce inflammable air, the Thermolamp conveyed gas via pipes around the home to provide lighting when the gas jets were lit at their extremities. The retort also provided heat.

Although it was a more domestic development of the kinds of uses being proposed by Diller, Lebon still understood his invention as conducive to new forms of pyrotechnics. Publicity for the Thermolamp claimed:

> We may very easily judge that with an inflammable principle so very docile and active, we can produce the most magnificent illuminations. Streams of fire well disposed; their durability, colour, and form, changing at pleasure: the movements of suns and columns must produce the most wonderful effect – What amazing advantages above the common illuminations![38]

Lebon also argued that gas gave 'inoffensive' light, and multicoloured displays:

> [The light is not]… tarnished by the least black or smoke. Its natural colour being white, may also vary, and become red, blue, or yellow: hence this variety of colours… may here become the constant effect of art and calculation.[39]

Such claims were not restricted to promotional literature. From 1799 Lebon gave numerous performances promoting the Thermolamp, exhibiting them for sale in gardens decorated with thousands of gas jets in the form of flowers and fountains.[40]

A famous visit to these shows led to the spread of gas-lighting in England. In 1802, Friedrich Winzer, a trader enjoying the patronage of the court of Brunswick, visited Lebon and took a version of the Thermolamp to London,

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[37] On Lebon and the thermolamp see F. A. Winsor, *Description of the Thermolamp invented by Lebon of Paris, Published with remarks by F. A. W.* (Brunswick, 1802); Philipe Lebon, *Thermolampe ou poêle qui chauffe et éclaire avec économie et offre avec plusiers produits précieux une force motrice applicable à toutes sortes de machines* (Paris, 1801); M. Eugene Defrance, *Histoire de l'éclairage des rues de Paris* (Paris: Imprimerie Nationale, 1904), pp. 91-97; on Lebon's 1799 patent, see 'Pour de nouveaux moyens d'employer les combustibles plus utilement, soit pour la chaleur, soit pour la lumière, et d'en recueillir les divers produits,' *Description des machines et procédés spécifiés dans les brevets d'invention, de perfectionnement et d'importation*, 413 vols. (Paris, 1811-1902), Vol. 5 (Paris, 1823), pp. 123-133.

[38] The quotation is from Winsor's translation of extracts from Lebon's promotional literature, in F. A. Winsor, *Account of the most ingenious and important national discovery for some ages* (London, 1804), p. 35.

[39] F.A.Winsor's translation of Lebon, *Account of the most ingenious… discovery*, p.33.

[40] M. Eugene Defrance, *Histoire de l'éclairage*, p. 93; F.A. Winsor, *Account*, p.40; Francis William Blagdon records that the gas flames were displayed 'on the garden façade of M. Lebon's residence'. *Paris as it was and as it is, or a sketch of the French capital… Vol. I: comprising also a correct account of the most remarkable national establishments and public buildings* (London, 1803), p. 27.

now selling it as the 'British Imperial Patent Stoves… for producing sevenfold Heat, and beautiful Light'.[41] Winzer's stove produced coal-gas for its effects, soon the subject of more spectacular performances. Adjusting his name for British audiences, Frederick Albert Winsor repeated much of Lebon's act, presenting gas as both a source of domestic light and heat and a new form of pyrotechnics. In fact, Winsor's performances were even closer to Diller's than Lebon's, something which critics would soon pick up on.

Winsor used the same venue as Diller, the Lyceum theatre in London, to advertise his stoves, and like Diller, Winsor trained assistants who travelled about the country exhibiting what they now called the 'philosophical lights'.[42]

There was still no boundary between utility, gas-lighting and spectacle, as Winsor's promotional pamphlets for the new stoves testify. 'The most brilliant fire-works are the delight of some minutes at an *extravagant expense*; but a light stove will yield a lasting fire and flame, in all manner and form that taste or fancy may direct; and at no expense, if the products gained are applied to useful purposes'.[43] Fireworks and illuminations made with gas would 'cherish the soul, and create good humour, by uniting conveniency, utility, and pleasure'.[44]

In these proposals, Winsor shifted the emphasis of gas-lighting further towards commercial ends, but his invention still followed the tradition of philosophical fireworks closely. The same was true of Winsor's future competitor, the Scottish engineer William Murdoch. In March 1802 Murdoch joined his long-term partners Matthew Boulton and James Watt in Birmingham to celebrate the Peace of Amiens with a spectacular illumination of the Boulton and Watt manufactory at Soho. A mixture of gas-lights and traditional illuminations lit up the front of the factory in what is often alleged as the first public exhibition of gas-lighting in Britain.[45]

The event has been viewed as an aberration in Murdoch's career, ill-fitting his image as a sober industrial genius. But gaslights and other philosophical fireworks appeared locally long before the Soho display. Balloon ascents with fireworks and festive coal bonfires were common in the area, while Diller's show reached Birmingham in 1789. A short time before, Boulton had exploded gas balloons over Soho, using long-fused squibs in an experiment 'to determine

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41 F.A. Winsor, *Account*, p. 12; Winsor's early career is described in Dean Chandler and A. Lacey, *Rise of the gas industry*, pp. 132-6.

42 Dean Chandler and A. Lacey, *Rise*, pp. 27-30; F. A. Winsor, *The superiority of the new patent coke over the use of coals, in all family concerns, displayed, every evening, at the Large Theatre, Lyceum, Strand, by the new imperial patent light stove* (London, 1804).

43 F.A.Winsor, *Account*, p. 23.

44 Ibid., p. 24.

45 For various appraisals, see Charles Hunt, *History of the introduction of gas lighting*, pp. 63-6.

whether the growling of thunder is owing to echoes, or to successive explosions'. Watt saw the explosion three miles away, noting it 'exhibited a fine firework' when it blew up.[46] Murdoch was hardly isolated from philosophical fireworks, and his own were no aberration. Theatre, philosophy, manufactures, and fireworks already intersected in Birmingham, just as they did in London and Paris.

In fact, it was only as late as 1805, following more than a decade of inflammable air fireworks, that the intimate relationship of gas-lighting with theatrical performance began to change. This occurred as protagonists moved away from the theatres of London and Birmingham and into elite addresses and establishment sites like the Houses of Parliament and Inns of Court. Such sites employed their own forms of theatre – the spectacle of the scaffold underwrote the law, while parades and trumpery goaded electorates at the Hustings.[47] But links to popular theatricals, like the carnival of Bartholomew Fair, could be evoked to ridicule political competition, and as Murdoch and Winsor began seeking ever grander profits from gas-lighting, so they began to compete. Claiming entertainments as vulgar and tying one's opponent to them then became a potent strategy for establishing elite credibility.

The technology of gas-lighting was first to change. Lebon and Winsor's patent stoves reflected fireworks practice by offering 'inoffensive' gas apparatus to be set up in the home. However, unlike temporary displays of gas or gunpowder fireworks, these installations were permanent, and needed to work regularly. They did not. By 1806, leaking pipes, irregular combustion of coal, and the problem of containing and dispensing with the sulphurous fumes given off in the burning process were making Winsor's gas stoves unreliable and customers cautious.[48] Consequently, Winsor changed tactics, moving from the Lyceum to premises in exclusive Pall Mall, and gathering subscribers to promote a new incorporated monopoly, the 'National Gas Light and Heat Company'.[49] Winsor's plans followed closely the structure of recently lucrative

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[46] Quoted in Jenny Uglow, *The lunar men: the friends who made the future* (London: Faber and Faber, 2002), pp. 372-3; John Langford, *A century of Birmingham life*,vol. I, p. 399; Robert K. Dent, *Old and new Birmingham, a history of the town and its people* (Birmingham, 1880), p. 197.

[47] Jean-Christophe Agnew, *Worlds apart: the market and the theater in anglo-American thought, 1550-1750* (New York: Cambridge University Press, 1986).

[48] M.E. Falkus, 'Early development of the British gas industry,' pp. 229-30.

[49] F. A. Winsor, *A National Light and Heat Company: for providing our streets and houses with light and heat, on similar principles, as they are now supplied with water, demonstrated with the patentee's authority and instructions, by Professor Hardie, at the Theatre of Sciences, No. 98, Pall Mall…* (London, 1806); idem*, Resolutions on Forming a National Light and Heat Company* (London, 1807); idem, *To be sanctioned by act of Parliament: a National Light and Heat Company, for providing our streets and houses with hydrocarbonic gas-lights… to be had at the National Light & Heat Company's office, no.97, Pall Mall* (London, 1807).

projects in water supply. Instead of every household using a stove, homes and streets would be furnished with gas by a network of underground pipes linked to a central supply station.[50] The link to 'inoffensive' indoor fireworks was thus broken as Winsor extended his ambitions.

Nevertheless, Winsor continued to put on a performance, as advertising for the venture included spectacular gas-illuminations at Carlton House to celebrate the Prince of Wales's birthday, followed by a display of thirteen gas street-lamps in Pall Mall, presenting an 'elegant appearance' in late 1807.[51] Upper-crust customers flocked to the shows, and after the Carlton House illuminations, Winsor sold thousands of shares in his scheme. Wealthy investors converted public spectacle into elite display. 'What folly to have a diamond necklace or a Corregio and not light your house with gas… better to eat dry bread by the splendour of gas, than to dine on wild beef with wax candles'.[52]

The Winsor-Murdoch dispute

In 1807, Winsor's schemes began drawing the attention of Boulton, James Watt jr. and William Murdoch. The Birmingham men were developing their own schemes for industrial gas-lighting by now, Murdoch having set up his first factory gas illumination two years earlier, at the cotton mill of Messrs Phillips and Lee in Manchester, with contracts in other manufacturies following.[53] Seeing Winsor's plans for a monopoly as a major threat to their operations, the Birmingham men began a concerted campaign to see him off. In 1808, a series of attacks launched on Winsor's schemes prompted the setting up of a House of Commons committee to investigate Winsor's bill seeking incorporation for his intended company.[54] Winsor and Murdoch now became embroiled in a dispute, provisionally over the patent for Winsor's gas stove, taken out in 1804, and the foundation of his monopoly claim. This led to further renegotiations of the status of gas-lighting. In the Commons, Murdoch

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[50] F.A. Winsor, 'To be sanctioned,' p.7; See also Wolfgang Schivelbusch, *Disenchanted night*, p.27.

[51] The lights are described in *Atheneum*, 1st January 1808, p.74.

[52] Quoted in John Griffiths, *The third man*, p. 266. See also the remarks of Lady Bessborough, writing to Lord Granville Leveson Gower, 7th September 1807, in *Lord Granville Leveson Gower (first earl Granville): private correspondence, 1781 to 1821*, ed. Castalia, countess Granville, 2 vols. (London: John Murray, 1916), II, p. 281.

[53] Boulton, Watt and Murdoch had stock of some 4000 burners and 30,000 feet of pipes by 1807, John Griffiths, *The third man*, p. 267.

[54] *Minutes of evidence taken before the committee to whom the bill to incorporate certain persons for procuring coke, oil, tar, pitch, ammoniacal liquor, essential oil and inflammable air from coal, and for other purposes, was committed* (London, 1809); For an overview of the proceedings, see Charles Hunt, *History of the introduction of gas lighting*, pp. 121-141.

and Winsor struggled to link each other's projects to Diller's popular theatricals, while claiming the distinction of commercial innovation for themselves. Only as a result of these contests, would theatricality and fireworks be cast as entirely distinct from, and inferior to, industrialised gas-lighting.

Boulton and Watt had much experience in the arena of patents. In 1799, Watt had succeeded in patenting the separate condenser, a victory for Boulton & Watt, and part of a larger battle over the definition of patent law.[55] Since the reign of James I, the Statute of Monopolies had granted patents only to original inventors and persons founding new manufactures in England, with no room for patenting more abstract applications or rearrangements of existing methods to new ends. Boulton and Watt argued vigorously for the latter, with the result that by 1800, patent law was ill-defined.[56] In typical cases, critics did their best to label undesirable inventors as 'projectors' summoning up bad memories of the South Sea Bubble and failed financial schemes.[57] Inventors defended themselves with claims of scientific respectability and originality in application. Disputes kept the definition of invention under constant negotiation, and resolutions inevitably depended less on firm definitions than on complex lobbying from the parties involved. Winsor and Murdoch's contest would be just such a case.

The contest hinged on manipulating the scope of patent law. Murdoch's allies began the dispute. In his *Journal of natural philosophy*, William Nicholson attacked Winsor's 1804 patent, arguing that gas-lighting

> … was.. shewn in public, anno 1784, by Diller and others, Mr. Murdoch… extensively applied this practice in Cornwall in 1792… [Winsor] is not the first inventor as to the public use and exercise thereof, and therefore his patent is void by statute of James the First.[58]

[55] James Patrick Muirhead, *The life of James Watt* (New York, 1859), pp. 303-14; Eric Robinson and Douglas McKie, eds., *Partners in science: letters of James Watt & Joseph Black* (London: Constable, 1970), passim; David Philip Miller, "Puffing Jamie': the commercial and ideological importance of being a 'philosopher' in the case of the reputation of James Watt (1736-1819),' *History of science* 38 (2000): 1-24.

[56] Statute of Monopolies, 1624, 21 Jac.1 c.3, section 6. On the origins and applications of the statute, see Christine MacLeod, *Inventing the Industrial Revolution, the English patent system, 1660-1800* (Cambridge: Cambridge University Press, 1988), pp. 14-19. On patent controversy, see ibid, pp. 58-74; H. I. Dutton, *The patent system and inventive activity during the industrial revolution, 1750-1852* (Manchester: Manchester University Press, 1984), pp. 68-84.

[57] See e.g. J. T. Desaguliers' remarks in A. J. G. Cummings and Larry Stewart, 'The case of the eighteenth-century projector: entrepreneurs, engineers, and legitimacy at the Hanoverian court,' in *Patronage and institutions; science, technology and medicine at the European court, 1500-1750*, Bruce T. Moran, ed. (New York: Boydell Press, 1991), pp. 235-261, on pp. 236-7.

[58] *A Journal of natural philosophy, chemistry, and the arts* 16 (1807): 73-4.

Nicholson thus denied Winsor's priority by invoking the old idea that only a first inventor warranted protection. Winsor responded by denying any comparison between his own and Diller or Murdoch's schemes. 'All Gas-lights shewn and exhibited before my illuminating the large Theatre in the Lyceum, early in 1804, I fairly consider as so many *Will-o'-the wisp* lights'.[59] This would include both Diller's fireworks and Murdoch's gas-lighting.

Murdoch also used the ambiguity of the patent system to attack Winsor. While Nicholson attempted to destroy Winsor's credibility as an innovator, Murdoch sought to bolster his own. Further rejecting Winsor's claims to any 'original discovery', in February 1808 Murdoch arranged a reading before the Royal Society of an account of his gas-lighting experiments in Phillips & Lee's manufactory. The paper was published in the *Philosophical transactions*, undoubtedly as evidence of a respectable priority claim, which the Royal Society cemented by awarding Murdoch a Rumford Medal for his work.[60]

Narrow definitions of patent law served to attack Winsor, but when it came to his own priority claims, Murdoch pushed the broader definition, recently successful for Watt. Rather than argue for the originality of his invention, Murdoch proposed it as the first *application* of gas-lighting to 'economical purposes' by lighting manufacturies. For good measure, Murdoch also denied any knowledge of prior gas-lighting schemes, locating the origin of his own gas work in isolated experiments at Redruth in 1792.

> At the time I commenced my experiments, I was certainly unacquainted with the circumstances of the gas from coal having been observed by others to be capable of combustion… but… I believe I may, without presuming too much, claim both the first idea of applying, and the first actual application of this gas to economical purposes.[61]

Diller's philosophical fireworks now became a critical issue in Murdoch and Winsor's debates. Despite condemning Diller's fireworks as '*Will-o'-the wisp* lights', Winsor sought to fend off Murdoch's accusations that his

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[59] F. A. Winsor*, Mr. W. Nicholson's attack, in his Philosophical Journal, on Mr. Winsor and the National Light and Heat Company, with Mr. Winsor's defence* (London, 1807), reproduced in Dean Chandler and A. Lacey, *Rise of the Gas Industry*, pp. 137-9, here p. 137. See also Charles Hunt*, History of the introduction of gas lighting*, pp. 110-11.

[60] *In Parliament: Gas-Light Bill* (London, c.1809), p. 5, possibly authored by Murdoch's lawyer Henry Brougham, stated Winsor and company 'have not made any new discovery or invention – This is admitted on all hands. Next, they have not made any new application of any former discovery'. William Murdoch, 'An Account of Application of the Gas from Coal to economical Purposes… Communicated by the Right Hon. Sir Joseph Banks, Bart. K.B. P.R.S.*,' Philosophical transactions of the Royal Society of London* 98 (1808): 124-132.

[61] William Murdoch, 'An account of application,' p. 132.

gaslight schemes were unoriginal with a repeat of Murdoch's own tactics. As the Commons committee hearings got under way, Winsor, in a short pamphlet, agreed with Murdoch that the dispute was about the application of gas to economic purposes, rather than its original discovery. However, he then identified Diller as the first to make the application, denying Murdoch's priority,

> Mr. Murdock… has no claim to the merit thus imputed to him, – for a German, of the name of Diller, so long ago as 1788, exhibited… what he called Philosophical Fire Works, – which were produced by inflammable Gas, generated in retorts, or stoves, and conveyed, by pipes, to the place of exhibition… Within a few years after this, the economical use to which this property of inflammable Gas may be applied, was communicated to the *Académie Royale des Sciences*, at Paris. This Notice was published by the Academy; and, afterwards, mentioned in the periodical publications of this country.[62]

This was a reasonably accurate account of Diller's career, but Winsor made no mention of his own debts to Diller's fireworks. Instead, he claimed Murdoch had plagiarised Diller, 'all he did was to add to the length of Mr. Diller's pipes, and proposed lighting a manufactory'.[63] Murdoch, said Winsor, was a 'mere adventurer', that most dreadful of business appellations, a projector.[64]

Murdoch was incensed, and responded with a letter addressed to the Commons committee. Reiterating his claim to be the first to apply gas-lighting, rather than to be its discoverer, Murdoch lambasted the committee for taking Winsor's claims seriously. Murdoch now contrasted his gas-lighting schemes directly with Diller's theatricality, reducing what contemporaries had seen as 'an epoch in natural philosophy' to the status of a 'puppet show',

> Did the German *Diller*, by his philosophical fire-works… by 'his large lustres of little flames…' exhibited for the amusement of the curious and ignorant, make the application of gas to purposes of public and private *utility*; guarding, as I am informed he did… his mode of proceeding, with all the mercenary caution of a juggler? Can the Gas-Committee set this puppet-show entertainment up against my practical application of the gas from coal…?[65]

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[62] F. A. Winsor, *Remarks upon the Bill for incorporating the Gas Light and Coke Company* (London, 1809), pp. 3-4.

[63] F. A. Winsor, *Remarks upon the Bill*, p. 4.

[64] Ibid., p. 6.

[65] William Murdoch, *A Letter to a Member of Parliament from Mr. William Murdock, in vindication of his character and claims; in reply to a recent publication by the Committee for conducting through Parliament a Bill for incorporating a Gas-light and Coke Company* (London, 1809), reproduced in Dean Chandler and A. Lacey, *Rise of the Gas Industry*, pp. 120-122, here p. 120.

Murdoch repeated the argument that it was really Winsor who was 'the successor of Mr. Diller'. His proposals were mere projects. As Murdoch put it: 'Does not this… call to our recollection the idea of the South-Sea Bubble?'[66]

By this point, both Winsor and Murdoch had claimed Diller's priority over their opponents' projects, but denied any connection to Diller when the accusation was levelled at them! Diller's shows were authentic inventions when used in accusation, but insignificant wonders when invoked in defence. Any link to Diller made an opponent into a projector, a showman entertainer not to be trusted.

Next came the opinions of the men of science. To bolster their claims, both Murdoch and Winsor made a spectacle of their scientific credentials to the Commons committee, pulling in the cream of establishment natural philosophy to argue their case. Henry Brougham, philosopher turned Whig barrister, represented Murdoch on the Commons committee, and Humphrey Davy and John Dalton were drawn in by Watt jr as witnesses to the propriety of Murdoch's science. Winsor followed suit, mustering the emigré German chemist Frederick Accum to argue his case. Evidently, the committee found Accum's evidence convincing, because they concluded in Winsor's favour.[67] It was not self-evident to the committee that Murdoch's case was valid. But their recommendations still had to pass through the House.[68]

There was little to choose between Murdoch and Winsor's schemes, as both sides in the dispute used similar accusations and claims to forward their cases. In the process, both protagonists had solidified a contrast between theatricality and industry in the business of gas-lighting. What had been an applauded continuum of spectacular and useful practice right up to 1805 was now split apart and heirarchised as contestants tried to distance themselves from competitor's claims to priority. This had occurred as the sites and stakes of gas-lighting changed, shifting from the theatres of London and Birmingham to the respectable addresses and government establishments of the capital. The move led to changes in gas technology, away from the model of philosophical fireworks towards models of water supply, and had created a contest where links to theatricality served to denigrate opponents. Both Winsor and Murdoch made this transition from theatre to commercial supply, and both employed identical tactics to obscure these roots and claim scientific and inventive respectability. But Winsor ultimately lost. While the committee

66 William Murdoch, *Letter*, p. 121.

67 For Accum's subsequent convictions, see William Ashworth's essay in this volume.

68 On the committee hearings see 'Minutes of evidence,' and John Griffiths, *The third man*, pp. 269-270.

found in Winsor's favour, the Commons did not. In June 1809, despite the committee's recommendations, constant lobbying from Brougham, Boulton and Watt led the House to throw out Winsor's bill on third reading, though only by a slender majority.

Even then, the following year saw a second restricted bill succeed, and two years later the London and Westminster Chartered Gas Light and Coke Company was founded.[69] Winsor however was not on the board. The failure of the first bill had been enough to make Murdoch's accusations stick and Winsor was condemned as a showman projector. As one pro-Murdoch pamphlet put it, 'The real history of this Bill is very short and plain. Mr. Winsor's puffs and projects have at last failed'.[70] Winsor used 'at least as much puffing as ever was practised by the South Sea projectors, or the purchasers of the Lottery'.[71] Winsor's proposals were nothing more than one of 'the delusive projects of foreign adventurers,' to be set down in the nineteenth-century imagination as an exemplary instance of projecting.[72]

Conclusion

The defeat of Winsor's bill left the Brunswick inventor a projector, and Murdoch a national hero. Commentators and historians would reproduce the contrast from then on. Murdoch's retrospective of the history of gas-lighting as the product of his isolated experiments in Cornwall became common currency, and the inventive intersections of philosophy, pyrotechny, theatre and manufactures were forgotten. Diller warranted occasional mention, but invariably on 'establishment' terms. Charles Hunt's 1907 *History of the introduction of gas lighting* noted Diller's shows in Birmingham, but thought 'this exhibition… served no useful purpose. It was but a nine days' wonder'.[73]

Yet theatrical shows of philosophical fireworks were a key site from which gas-lighting emerged, and indeed, they did not disappear even as the contest between Winsor and Murdoch concluded. In 1814 the government staged Britain's grandest firework since the 'grand whim', as Tory inventor and artillery chief Sir William Congreve set off impressive fireworks in London to mark victory celebrations over the fall of Napoleon. Gas illuminations formed the centrepiece of his display. A Chinese pagoda was erected in Hyde Park and fitted with pipes on each storey, with projections 'in the form of a griffin's

69 John Griffiths, *The third man*, pp. 270-272;

70 *In Parliament: Gas-Light Bill*, pp. 10-11.

71 Ibid., pp. 11-12.

72 Ibid., p. 12.

73 Charles Hunt, *History of the introduction of gas lighting*, p. 20.

head, pierced with small holes, through which issued jets of gas'.[74] Congreve intended the pagoda to publicise gas-lighting to a public who remained suspicious of the new technology. But the show was a flop. Congreve's pagoda accidentally caught fire and burned to the ground, suffering the same fate as the 'grand whim' of 1749, which had been the spark for the original turn to philosophical fireworks.

The career of philosophical fireworks explored in this essay sheds light on the process by which the theatricality of eighteenth-century philosophy was transformed into economic utility in the early nineteenth century. Rather than simply oppose the spectacle of the *ancien regime* to the economics and utility of the industrial era, it is more instructive to see them both developing and intersecting continuously, but at different levels. Theatre and showmanship never receded, as Congreve's performance testifies, but when their objects moved to different sites and social arenas, they could be transformed into seemingly unspectacular industrial technologies. Different contexts entailed different decorum. In spectacular venues like gardens and theatres, performers' dexterity, novelty, and wonder marked the bounds of evaluation for gaseous inventions. But in exclusive addresses and Commons committees, calculated profits, priority claims, and the establishment of scientific credibility were more suitable. Gas-lighting moved in and out of these arenas, prompting continuous efforts to alter its definition and meaning accordingly.

Primary sources

A letter to a member of Parliament from Mr. William Murdock, in vindication of his character and claims; in reply to a recent publication by the Committee for conducting through Parliament a Bill for incorporating a Gas-light and Coke Company (London, 1809).

A National Light and Heat Company: for providing our streets and houses with light and heat, on similar principles, as they are now supplied with water, demonstrated with the patentee's authority and instructions, by Professor Hardie, at the Theatre of Sciences, No. 98, Pall Mall… (London, 1806).

Adams, George, *Lectures on natural and experimental philosophy*, 5 vols. (London, 1794).

An heroic epistle to Mr. Winsor, the patentee of the hydro-carbonic gas lights and founder of the National Light and Heat Company (London, 1808).

Atheneum.

Avant-Coureur.

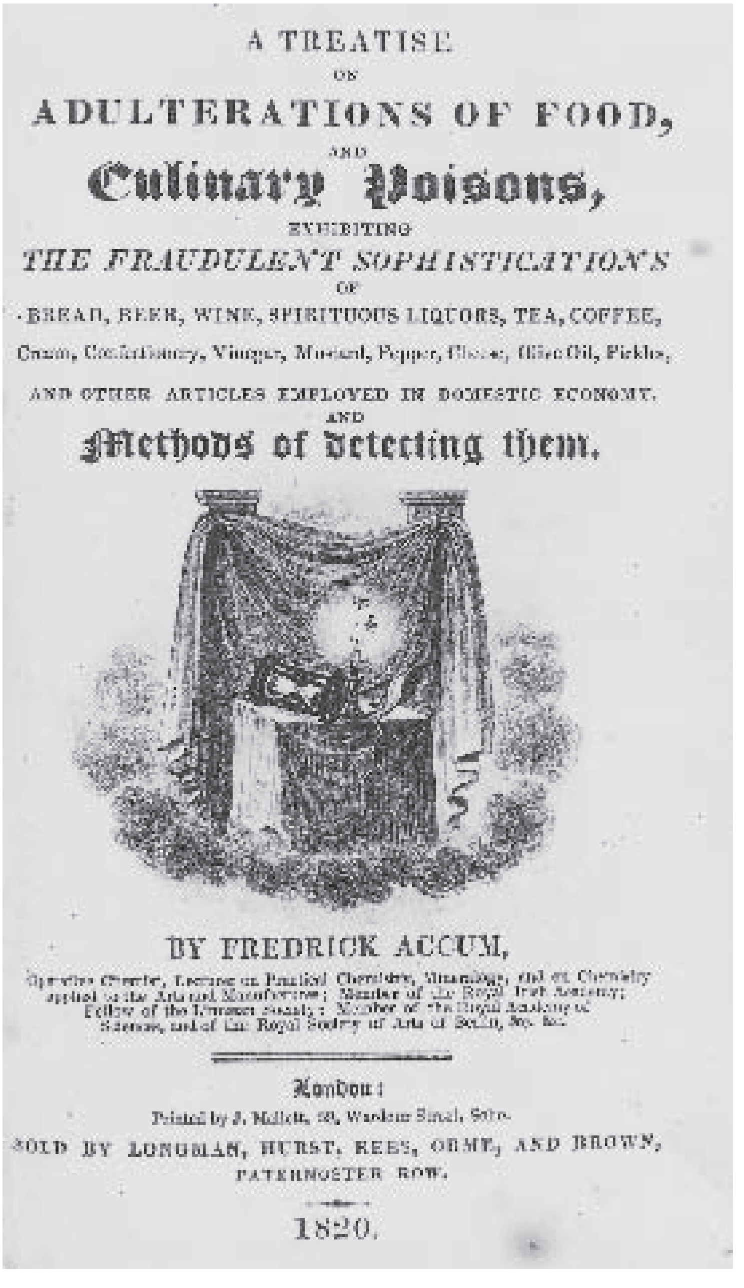
Blagdon, Francis William, *Paris as it was and as it is, or A sketch of the French capital… Vol. I: comprising also a correct account of the most remarkable national establishments and public buildings* (London, 1803).

Clegg jr, Samuel, *A practical treatise on the manufacture and distribution of coal-gas* (London, 1841).

[74] Samuel Clegg jr, *A practical treatise*, p.19; on the pagoda, see Suzanne Boorsch, 'Fireworks on paper: celebration of the 'Glorious Peace', London 1814,' *Art On Paper* 4 (2000): 54-59.

Cristóbal, José María San and Josep Garriga i Buach, *Curso de química general aplicada a las artes*, 2 vols. (Paris, 1804-1805).
Description des machines et procédés spécifiés dans les brevets d'invention, de perfectionnement et d'importation, 413 vols. (Paris, 1811-1902).
Gentleman's Magazine.
Guyot, Edme-Gilles, *Nouvelles récréations physiques et mathématiques, contenant ce qui a été imaginé de plus curieux dans ce genre et qui se découvre journellement* (Paris, 1799).
Heal Collection of Trade Cards and Shop Bills, British Museum.
In Parliament: Gas-Light Bill (London, c.1809).
Jones, Robert, *A new treatise on artificial fireworks* (London, 1765).
Journal de Paris.
Journal encyclopédique ou universel.
Lacombe, Jacques, *Dictionnaire encyclopedique des amusemens des sciences* (Paris, 1792).
Lebon, Philipe, *Thermolampe ou poêle qui chauffe et éclaire avec économie et offre avec plusiers produits précieux une force motrice applicable à toutes sortes de machines* (Paris, 1801).
Lysons, Rev. Daniel, *Collectanea, or, A Collection of Advertisements and Paragraphs From the Newspapers, Relating to various Subjects*, 5 vols, British Library.
Matthews, William, *An historical sketch of the origin, progress, and present state of gas-lighting* (London, 1827).
Mémoire sur les feux d'air inflammable par M. Diller. Extrait des Registres de l'Académie Royale des Sciences, du 4 Juillet 1787 (Paris, 1787).
Mercure de France.
Minutes of evidence taken before the committee to whom the bill to incorporate certain persons for procuring coke, oil, tar, pitch, ammoniacal liquor, essential oil and inflammable air from coal, and for other purposes, was committed (London, 1809).
Mr. Diller's grand exhibition of new-invented philosophical fireworks from inflammable air, exhibited… at the Lyceum, near Exeter 'change, Strand (London, 1787).
Mr. Flockton's Theatre. At the [White Lyen Highgate] *in this town. This present evening, will be exhibited his grand exhibition, in the same manner as performed before the Royal Family and most of the nobility in the kingdom* (London, c.1780).
Mr. W. Nicholson's attack, in his Philosophical Journal, on Mr. Winsor and the National Light and Heat Company, with Mr. Winsor's defence (London, 1807).
Murdoch, William, 'An Account of application of the gas from coal to economical purposes… communicated by the Right Hon. Sir Joseph Banks, Bart. K. B. P.R.S.,' *Philosophical transactions of the Royal Society of London* 98 1(808): 124-132.
Oeuvres de Lavoisier, ed. Edouard Grimaux, 6 vols. (Paris, 1862-93).
Peckston, T. S., *The theory and practice of gas-lighting in which is exhibited an historical sketch of the rise and progress of the science* (London, 1819).
Perrinet d'Orval, Jean Charles, *Essay sur les feux d'artifice pour le spectacle et pour la guerre* (Paris, 1745).
Remarks upon the Bill for incorporating the Gas Light and Coke Company (London, 1809).
Resolutions on forming a National Light and Heat Company (London, 1807).
Ruggieri, Claude-Fortuné, *Précis historique sur les fêtes, les spectacles et les réjouissances publiques* (Paris, 1830).
Saturday Evening Post (Philadelphia).
The Analytical Review, or history of literature, domestic and foreign.
The Euterpeiad; or, musical intelligencer, and ladies gazette (Boston).

The Green-Park folly, or the fireworks blown up: a satire (London, 1749).
The Scots Magazine.
The superiority of the new patent coke over the use of coals, in all family concerns, displayed, every evening, at the Large Theatre, Lyceum, Strand, by the new imperial patent light stove (London, 1804).
Times of London.
To be sanctioned by act of Parliament: a National Light and Heat Company, for providing our streets and houses with hydrocarbonic gas-lights… to be had at the National Light & Heat Company's office, no. 97, Pall Mall (London, 1807).
Universal Magazine.
Winsor, Frederick A., *Account of the most ingenious and important national discovery for some ages* (London, 1804).
Winsor, Frederick A., *Description of the Thermolamp invented by Lebon of Paris, published with remarks by F. A. W.* (Brunswick, 1802).



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THE FRAUDULENT SOPHISTICATIONS
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A textual map of the hidden world of food and drink adulteration: Fredrick Accum, *A treatise of adulteration of food, and culinary poisons* (London, 1820). Courtesy of Special Collections Archive, University of Liverpool Library.

The intersection of industry and the state in eighteenth-century Britain

William J. Ashworth

In 1825, the seemingly out-of-date political commentator David Robinson warned that free trade policies would be a disaster for British industry, and dismissed the idea that foreign competition would improve domestic industry by forcing it to innovate. He wrote:

> The greatest improvements have been made in our manufactures when they have been the most free from [foreign] competition…. Our cotton manufacturers have made the greatest varieties in their articles, and the greatest reductions in their prices, when it has been perfectly unknown. Our iron and several other articles, which a few years since were greatly inferior to those provided in other countries, have been brought to equal, and in some cases to surpass those of all other parts, entirely without such competition. Under a system which studiously prevented such competition, which jealously excluded the foreigner from our home market, we have far outstripped all other nations in manufactures… we have rendered ourselves the first manufacturing nation in the universe.[1]

Conversely, Robinson's leading political antagonist and fierce exponent of free-trade, Henry Parnell, was absolutely convinced that 'nothing can be more opposite to the truth than the statement in the Report of the late French Commission of Inquiry, that 'England has only arrived at the summit of prosperity by persisting for centuries in the system of protection and prohibition".[2] However, perhaps Robinson and the French had a point. In 1640, England was a weak second-rate power with a small and backward industrial base. Just over two hundred years later it was the world's foremost industrial and imperial power. An economic policy revolving upon the navy, colonies, credible long-term borrowing, tariff protection and the excise had put Britain into a seemingly invincible industrial and commercial position.[3]

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[1] David Robinson, 'The silk trade,' *Blackwood's Edinburgh Magazine* 18 (1825): 736-50, on p. 743.

[2] Henry Parnell, *On Financial Reform* (London, 3rd edn., 1831), p. 82.

[3] An excise, strictly speaking, is a tax on goods manufactured or grown domestically. It is meant to be a duty on inland goods as distinct from customs levied on imported commodities. However, this definition does not clearly hold for the period surveyed here, in particular, certain imports came

A dramatic restructuring of tax policy during the first half of the nineteenth century was only made possible by a general confidence in the ability of Britain's entire industry, old and new, finally to thrive in the world without a protective barrier. The former combination of protection and the nurturing of domestic industries had been so successful that the fact that many of these manufactures would not have existed without high tariffs was largely ignored by leading politicians. Indeed, while Britain was knocking down its industrial enclosure, other nations – most notably Germany and the United States – intensified or erected theirs. As the leading historian of Britain's free trade policies recently suggests: 'Arguably by the 1870s, the most logical 'cunning of the state' would have led Britain to consolidate her empire behind tariff walls in order to defend her industrial lead against the newly industrializing economies of the world; a policy belatedly formulated by Joseph Chamberlain in the early twentieth century'.[4]

There is a good case to make that Britain's industrial development was less the result of a distinctive indigenous mentality and the gift of mutating 'natural inquiry' into mastering nature; instead, it can be argued that it owed more to a policy of nurturing domestic industry behind a wall of tariffs, skill in imitating and subsequently transforming foreign (especially Asian) products, unparalleled exploitation of African slave labour, rich resources of coal, a monopoly of trade with British North America and aggressive military prowess. In many ways, the backbone of Britain's global might was luck and a stunningly successful fiscal system as compared to the rest of Europe.

The historiography of this age has, perhaps, yet to break free of its nineteenth-century nationalist shackles and Cold War prophets.[5] Its emphasis on English origins of the modern industrial process has neatly underpinned western liberalism on several occasions. During the Cold War, Walter W. Rostow's industrial blueprint for third world development took off under the title *The stages of economic growth*: *a non-communist manifesto*. For this important White House policy adviser and Presidential speech writer, the key to industrial take-off was

under the management of the excise, a situation lasting from 1643 to 1825 when most of the excised imports were transferred to the customs. To add to this confusion some exports during the English Civil War and Interregnum also paid an excise.

4 Anthony Howe, 'Restoring free trade, 1776-1873,' Donald Winch and Patrick K. O'Brien, ed., *The political economy of british historical experience* (Oxford, 2003), pp. 193-213, on p. 209.

5 Colin Kidd, 'Hybridity,' *London Review of Books* 26 (2 September 2004): 14-15, on p. 14. The problem of 'nationalistic undertones' in the debate over 'technological creativity and economic development' has also been underlined by Christine MacLeod in her essay 'The European origins of British Technological Predominance,' Leandro Prados de la Escosura, ed., *Exceptionalism and industrialisation: Britain and its European Rivals, 1688-1815* (Cambridge: Cambridge University Press, 2004), pp. 111-126.

Isaac Newton. Any country incapable of sustained economic growth was labelled 'pre-Newtonian'. Rostow wrote: 'By changing the way man looked at the world around him, the Newtonian perception increased, in ways impossible to measure, the supply of scientists, the supply of inventors, and the willingness of entrepreneurs to introduce innovation'. Without this transformation, industrial 'take-off' would be impossible. '[B]ehind the whole industrial process lies the acceptance of the Newtonian outlook, the acceptance of the world of modern science and technology'. Like his near contemporaries T. S. Ashton and David Landes and, more recently, Joel Mokyr and Margaret Jacob, Rostow's 'outlook' came together in an 'Industrial Enlightenment' in late-eighteenth century Britain.[6] No room here for mundane government protectionist and regulatory policies.

More recently, Roy Porter has reemphasized Britain's central role in forging the modern world, while Niall Ferguson's celebratory account of the British Empire, sub-titled *How Britain made the modern world,* demonstrates how British industriousness has benefited civilization in general.[7] Rostow's argument is most recently reborn in the work of Mokyr, with the substitution of that other Protestant Englishman, Francis Bacon, for Newton.[8] Whether rooted in 'Newtonian'or 'Baconian' science and technology, according to this view, industrially enlightened Britain inevitably moved toward free trade.

> In addition to the Baconian program, the [Industrial] Enlightenment produced what might best be called a doctrine of *economic reasonableness*, which became embodied in the tenets of political economy, and especially influenced policy makers in most Western economies. Economic reasonableness concerned issues of political economy such as free trade, improved infrastructure, law and order's effect on commerce, and more efficient, less distortionary taxes.[9]

As we re-assess the claimed boundaries between science, technology and industrialisation, however, we need to abandon such imagined distinctive

[6] Walter W. Rostow, *The beginnings of modern economic growth* (Oxford: Oxford University Press, 1953, 2nd edition, 1960), on pp. 559-562; idem., 'Leading sectors and the take-off,' in *The economics of take-off* (London: Macmillan Press, 1963), ed. Walter W. Rostow, pp. 1-21, on pp. 9-12; Margaret C. Jacob, *Scientific culture and the making of the industrial West* (Oxford: Oxford University Press, 1997). For David Landes's perspective in historical context see Leonard N. Rosenband, 'Never just business: David Landes, *The Unbound Prometheus*,' *Technology and culture* 46 (2005): 168-176.

[7] Roy Porter, *Enlightenment: Britain and the creation of the modern world* (London: Penguin Books, 2001); Niall Ferguson, *Empire: how Britain made the modern world* (London: Allen Lane, 2003).

[8] Joel Mokyr, 'The intellectual origins of modern economic growth,' *Journal of economic history* 65 (2005): 285-351, on p. 291 and *The gifts of Athena: historical origins of the knowledge economy* (Princeton: Princeton University Press, 2002), pp. 28-77.

[9] Joel Mokyr, 'The intellectual origins,' pp. 336-337.

national interpretations. Perhaps, more than ever, such accounts need to be challenged.[10]

The purpose of this essay is two-fold. It argues first that England/Britain pursued an industrial policy of protection and regulation during the eighteenth century. Second, in keeping with this aggressive regime of regulation and encouragement, it traces the state's formative impact, via the excise, on British industry. The sites where state and industry intersected saw the development of an approach to the measurement of goods for taxation that was characterized by what I have termed elsewhere 'practical objectivity'.[11] If 'practical objectivity' helped ease the state's gauging of revenue, it simultaneously informed the shape and method of production.

An eighteenth-century British economic policy?

To understand the fundamental intersection between the state and manufacturers we need to situate it within eighteenth-century British industrial policy. The recent work of Joseph Inikori and David Ormrod has convincingly shown that a combination of Atlantic overseas trade and a policy of import and re-export substitution lies at the heart of English/British industrialization during the eighteenth century. This is dramatically demonstrated by the fact that England imported 34.7 percent raw materials and 31.7 percent manufactures between 1699 and 1702, and 62.3 percent raw materials and a mere 4.3 percent manufactures by the mid-1840s.[12]

The origins of such a transformation, for Ormrod, lie in the 1670s and Parliament's attitude to the balance of trade. Prior to this decade, he argues, 'fiscal and commercial interests had run parallel, but hence forth, the Commons became more concerned with the balance of trade and the encouragement of native manufactures'. The policy of nurturing England's predominantly backward industries was forcefully underlined by the new and important Commission for Trade and Plantations. In its first report on the 'State of the

[10] For an excellent example of the porous nature of nationalist boundaries in the industrial development of one industry see Leonard N. Rosenband, 'The competitive cosmopolitanism of an old regime craft,' *French historical studies* 23 (2000): 455-76 and his essay in this book. This argument is generalised across industries in Christine MacLeod, 'European origins,' pp. 120-121. For 'imagined geographies' and their political force see D. Gregory, *The colonial present* (Oxford: Oxford University Press, 2004).

[11] William J. Ashworth, 'Practical objectivity: The excise, state and production in eighteenth century England,' *Social epistemology* 18 (2004): 177-93.

[12] David Ormod, *The rise of commercial empires: England and the Netherlands in the age of mercantilism, 1650-1770* (Cambridge: Cambridge University Press, 2003), pp. 141, 181-182, 317; Joseph E. Inkori, *Africans and the Industrial Revolution in England: a study in international trade and economic development* (Cambridge: Cambridge University Press, 2002), p. 363.

Trade of the Kingdom' in 1697, they argued for the need to encourage the silk, linen and paper manufacturers – 'that we may improve to make as good as what comes from abroad'.[13]

A massive impetus to the establishment of industrial protection and the nurturing of domestic industries came from the phenomenal growth in imported Indian calicoes during the 1680s and '90s. The 1690s also saw the implementation of numerous Acts of Parliament and regulations affecting forms of trade and industry, including the cloth industry. Significant parts of the English woollen interest – those primarily concerned with manufacturing lighter woollens – joined the weavers in East Anglia and the silk weavers of London and Canterbury in condemning the threat of imported French silks and Asian calicoes by the East India Company. Although the wool industry had powerful interests in the House of Commons, the East India Company was equally powerful in the House of Lords; the result was a compromise, with the introduction of a special duty of twenty percent on imports of cheap Indian and Chinese textiles, followed in 1701 by an actual prohibition of all Asian cloth that was painted, dyed, printed or stained. The Company could, however, still re-export such items and, crucially, plain calicoes could still be finished and sold in England (muslin was also still legal). This, in turn, stimulated the growth of English calico printing.[14]

This new domestic industry quickly began to imitate successfully the popular oriental designs and, according to the East India Company, could print the cloth at half the price charged for Indian goods. Indeed, a small industry established by French Huguenot immigrants had already commenced in 1676 copying East India Company calico imports – although far inferior in quality. Import duties were also placed on plain calicoes in 1701, followed by rises in 1704 and 1708, while excise duties were subsequently put on domestically manufactured printed calicoes in 1712 and 1714. Maxine Berg has recently argued that, in general, there 'is a sense in which much of the focus of invention during the eighteenth century was directed towards the process of imitation'. In contrast to England, the Dutch commercial interest overcame manufacturing interests and prevented the formation of tariff walls to protect an otherwise advanced calico industry. France, meanwhile, went in the opposite direction and regulated too harshly, preventing its profitable emergence.[15]

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[13] David Ormod, *The rise of commercial empires*, pp. 141, 173.

[14] P. K. O'Brien, T. Griffiths and P. Hunt, 'Political components of the Industrial Revolution: Parliament and the English textile industry, 1660-1774,' *Economic history review* 44 (1991): 395-423, on p. 398; H. F. Kearney, 'The political background to English mercantilism, 1695-1700,' *Economic history review* 11 (1959): 484-496, on pp. 485-86.

[15] E. Lipson, *The economic history of England*, 3 Vols, Vol. 3, (London: Black, 1943), pp. 41-42; Joseph E. Inikori, *Africans and the Industrial Revolution*, pp. 431-33. Maxine Berg, 'New commodities, luxuries

In addition to opposing calico imports, the powerful English woollen manufacturers had earlier started lobbying against the threats to its industry from Irish and New England woollen rivals. This, once again, pushed Parliament into action. The result was yet more pain for Ireland's ailing economy, resulting in the suppression of its wool in an Act of 1699. Instead, and perhaps informed by the 1697 report by the Commission for Trade and Plantations, the Irish were forcibly advised to cultivate and concentrate on building a linen industry, which along with Scotland became a low cost alternative producer to expensive European fabric makers and an additional import substitute for banned Asian printed calicoes. Linen imports were very lucrative, and clear savings could be made by creating a new supplier. Indeed, linen was the largest import in terms of value before it was replaced by sugar in the mid-eighteenth century. From about the 1730s, European imports of linen into England started to diminish greatly, while British and Irish linen also benefited in 1743 and 1745 with the introduction of bounties. The export of English linen grew from a value of £87,000 in 1740 to a very lucrative sum of over £200,000 by 1750. Here is a very good example of the English import substitution policy promoted by Parliament.[16]

Prohibitive duties also appeared on various French goods between 1693 and 1696, and were kept in force for nearly the whole of the eighteenth century. Again a measure designed to protect domestic industrial interests, these duties led to the substitution of English supplies for French silks, linens and white paper. Nonetheless, foreign suppliers still found it relatively easy to penetrate the English market through the vast illicit economy, what I prefer to call the 'common economy', or simply by shipping such goods under the cloak of another European country, most notably the Dutch Republic. Ideally, then, to fight the common economy required the production of goods of an equivalent quality – this, to a certain extent, was where manufacturing regulations and excise stipulations came in. Industry was later aided by the projects and premiums promoted by the Society for Arts, Manufactures and Commerce. In taxing infant industries such as spirits, paper, glass and soap, it was important, then, to aim at attaining the quality of foreign equivalents. It amounted to an

and their consumers in eighteenth-century England,' Maxine Berg and Helen Clifford, ed., *Consumers and luxury: consumer culture in Europe 1650-1850* (Manchester: Manchester Univ. Press, 1999), pp. 63-85, on p. 77, and 'From imitation to invention: creating commodities in eighteenth-century Britain,' *Economic history review* 55 (2002): 1-30. For the Dutch and French see P.K. O'Brien et al, 'Political components,' pp. 417-418.

[16] David Ormrod, *The rise of commercial empires*, pp. 143-44, 152-154, 168-169, 170-171; Joseph E. Inikori, *Africans and the Industrial Revolution*, pp. 421-425. The importance of sustaining social stability in both Ireland and Scotland played a large role in government policy concerning the linen industry, see P.K. O'Brien et al, 'Political components'.

ongoing battle, since the traders and, as we shall see, manufactures feeding the common economy were equally adept at imitation and innovation. The lessons of commerce were learnt in both the licit and alternative economies.[17]

Developing domestic industries also depended on acquiring the necessary skills. For certain manufactures this was solved by the huge influx of skilled Huguenot refugees during the 1680s and 1690s. Their role in paper-making and silk is well known, but they also spearheaded linen production in Ireland. Indeed, perhaps it was the arrival of skilled linen labour that gave the English government the confidence to suppress Irish wool and promote a new Irish linen industry. Skilled Protestant labour from the continent also informed the switch within the English woollen firms toward lighter and more finished woollen and worsted cloth. Many of these immigrants also came with impressive trading, banking and contracting credentials. Their capital and financial skills, in turn, helped support the costly Protestant war against Louis XIV.[18]

It was also during the 1690s that criticism of export duties began to emerge. The first to be abolished were export duties on woollen cloth, in 1700 – a clear attempt to place economic policy on an export footing. However, it was not until Robert Walpole's extensive customs reform of 1722, which abolished export duties on all British goods, that this objective really took root. By then, most export duties had been eradicated and a series of bounties had been enacted to stimulate home industry. Protective duties on competing manufactured imports were simultaneously increased, while primary materials produced at home were prioritised for the benefit of domestic industry. This all helped to strengthen and expand the excise.[19]

Meanwhile, the continual lobbying of woollen and silk interests resulted in the Calico Act of 1721, which legislated a total ban on all types of imported calicoes and, for good measure, made it illegal to wear such cloth. Printed calicos could still be imported for re-export, while plain calicos could be imported to be printed and re-exported. The Act also exempted the production and

[17] For the common economy see William J. Ashworth, *Customs and excise: trade, production and consumption in England 1640-1845* (Oxford: Oxford Univ. Press, 2003), pp. 131-205. For the role of the Society of Arts see Rosenband's essay in this volume and Maxine Berg, 'New commodities,' pp. 77-82.

[18] David Ormrod, *The rise of commercial empires*, pp. 91-92; C. Knick Harley, 'Trade: discovery, mercantilism and technology,' R. Floud and D. Johnson, eds, *The Cambridge Economic History* (Cambridge, Cambridge University Press, 2004), pp. 175-203, on p. 176.

[19] Ralph Davis, 'The rise of protection in England, 1689-1786,' *Economic history review* 19 (1966): 309-311; Charles Wilson, *England's apprenticeship 1603-1763* (London: Longmans, 1966), pp. 236-237, 267-269; Edward Hughes, *Studies in administration and finance, 1558-1825* (Manchester: Manchester University Press, 1934), p. 176.

printing of fustians (cotton mixed with flax or wool) in Lancashire. Due to the similarity of English fustian to Indian calico, manufacturers were able to exploit the demand in both domestic and European markets, especially in France where calico printing had been banned since 1686. The eventual winner in all of this was not wool but domestic linen and, ultimately, cotton. Indeed, as we have seen, the government was keen to encourage the excised, but tariff-protected, linen industry so as to offset European imports. Besides, to ban domestic production, as the woollen interests hoped, would have been catastrophic to a growing source of revenue as well as to social relations in Ireland, Scotland and several regions of England. Therefore the prohibition on East Indian textile imports, far from securing the domestic future of wool, actually stimulated the emergence of linen and cotton. Indeed, the archetypal representation of the Industrial Revolution, the cotton industry, was a product of state protectionist policies, additionally being only lightly taxed in comparison to other domestic industries.[20]

Protecting domestic industry, especially infant sectors, through high tariff duties may not have been a full-blown, systematically applied industrial policy, but it did represent a recognised, actively pursued and successful strategy. The protective barriers allowed manufactures to develop, which enabled the excise to expand as it farmed them; revenue collection became more efficient and, crucially, relatively predictable (in contrast to customs and the land tax), something essential for sustaining Public Credit. This point needs to be added to historians' general recognition that Great Britain's economy was more defined and integrated than most of its European rivals. Taken together, these factors explain higher employment levels, which alleviated the threat of domestic social unrest and a drain on the nation's bullion; this, in turn, made the country more self-sufficient at a time when it was so often at war.

As Patrick K. O'Brien has argued, the cultivation of home markets and their protection from foreign competition, removed much of the force from the organised pressure directed by manufactures against government taxation policies. 'In this respect,' he concludes,'excises were being collected at the

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[20] The key role of 'the visible hands of law and regulation' behind the rise of cotton is best described in P.K. O'Brien et al, 'Political components,' especially pp. 409-18, and Martin J. Daunton, *Progress and poverty: an economic history of Britain 1700-1850* (Oxford: Oxford University Press, 1995), pp. 539-545, 557; E. Lipson, *Economic history of England*, p. 44. See also Stanley L. Engerman, 'Mercantilism and overseas trade, 1700-1800,' R. Floud and D. McCloskey, ed., *The Economic History of Britain Since 1700*, 2 Vols., Vol. 1 (Cambridge: Cambridge University Press, 2nd edn., 1995),pp.182-204, on 189; S. D. Chapman, *The cotton industry in the Industrial Revolution* (London, 1972), 12-13; Pat Hudson, 'Industrial organisation and structure,' R. Floud and D. Johnson, ed., *The Cambridge economic history of modern Britain*, pp. 28-56, on p. 32.

expense of customs duties'.[21] Protectionist policies, then, made possible the fertility necessary to nurture domestic manufactures and the subsequent extensive taxing of its fruits, all of which – along with the specification of ingredients, production and system of gauging devised to measure commodities – was important in defining the shape of both taxed and eventually untaxed manufactures. Pragmatism appeared in the setting of domestic excise rates – here it was up to the manufacturers to lobby and secure the best rate they could at the expense of another industry or indeed within the same industry. England/Britain clearly pursued its revenue as part of a general economic policy. By contrast, as J. F. Bosher points out, France 'valued the customs for their financial yield. It treated them primarily as a tax rather than an instrument of economic policy'.[22]

A new economic policy

By the 1780s, however, the relations between the state and manufactures were becoming extremely strained. The policy of protection and the excise had reached its peak. William Pitt and his advisers had difficulties in finding new avenues for revenue, the only option being to keep hiking up the excise. However, the levy was now spilling over the protective tariff wall and some manufacturers were increasingly agitating for change. Aggressive lobbying intensified while manufacturing interests began to combine to produce an even more potent pressure group. Indeed, in the case of the coal tax, manufacturing interests flexed their muscle in such an unexpectedly powerful way that Pitt was forced to drop the tax within a week; the iron masters bitterly complained that the increase in coal duties would make it extremely difficult for British iron makers to compete with the Swedes. Another example comes from the government's policy on linens and calicoes, which was aggressively opposed by Manchester and Glasgow cotton manufacturers. They vented their fury when asked by the government to give evidence on the economic plan proposed for Ireland. They were willing to accept competition, but only if both countries were subject to the same regulations. The Manchester and Glasgow cotton men were instrumental in forming a General Chamber of Manufacturers, gaining the further support of iron founders from the Midlands and West of Britain. The aim was to be a national body that coordinated industrial policy

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[21] P. K. O'Brien, 'The political economy of British taxation, 1660-1815,' *Economic history review* 41 (1988): 1-32, on p. 14 and p. 27; Ralph Davis, 'Rise of protection,' pp. 306-317; Norris A. Brisco, *Economic policy of Walpole*, pp. 166-187.

[22] J. F. Bosher, *The single duty project: a study of the movement for a French customs union in the eighteenth century* (London: Ashlone Press, 1969), p. 95.

and influenced Parliament on behalf of domestic industry. However, there were too many diverse interests and clashes of opinion to sustain the body, which eventually dissolved during a bitter dispute over the proposed trade treaty with France in 1786.[23]

The impact of the new manufacturers on fiscal and industrial policy is extremely significant. The cotton industry had been given important concessions in 1774, including the removal of prohibitions and the go-ahead for Britons to wear or use goods wholly made of cotton. However, in 1784 an attempt was made to boost duties upon tax dyed stuffs of cotton and of cotton and linen mixed, and to require bleachers and dyers to purchase licences. It was less, however, the introduction of these new levies that rankled the cotton manufacturers than the fact that they were collected by the excise. This was a view that united all the new industries. The pottery manufacturer and entrepreneur Josiah Wedgwood wanted to see the excise 'annihilated'. He warned, 'Excise laws are the bane of manufacturers: the officers are spies upon all the operations of the artist: discoveries, which have been the fruit of great labour and expense to him, they convey to his rivals, perhaps foreign nations'.[24]

Very attractive offers were made by powerful Irish figures to woo English cotton manufacturers. Despite an attempt in England to level the playing field by putting countervailing duties on Irish imports, it was the mode of collection that cotton manufacturers primarily opposed. What was also novel in this debate – spearheaded by the new industries – was the view towards the market. Unlike older industries bred upon the culture of preserving and protecting primarily domestic markets, the cotton manufacturers in particular wanted to acquire new ones. Unlike the traditional excised industries, cotton had no real rivals at this stage (as long as the Irish were not privileged and the Indian cotton industry continued to decline), and therefore needed no protective barrier. The stakes grew and the difference between the Irish and British tax

[23] John Ehrman, *The Younger Pitt: the years of acclaim* (London: Constable & Co., 1969), pp. 252-253; J. M. Norris, 'Samuel Garbett and the Early development of industrial lobbying in Great Britain,' *Economic history review* 10 (1958): 450-460, on pp. 453, 458-59. For the ill-fated shop tax see H. Mui and L. H. Mui, *Shops and shopkeepers in eighteenth-century England* (London: Routledge, 1989), pp. 34-36, 73-85. The context, interests and reasons fuelling early industrial lobbying and the formation of manufacturing associations is usefully examined in Vivian E. Dietz, 'Before the age of capital: manufacturing interests and the British state, 1780-1800' (unpublished Ph.D. thesis, Princeton University, 1991).

[24] Will Bowden, 'The influence of the manufacturers on some of the early policies of William Pitt,' *American historical review* 29 (1924): 655-74, on p. 656, and *Industrial society in England towards the end of the eighteenth century* (London, 1925, 2nd edn., 1965), p. 170. Josiah Wedgwood is quoted in Vivian E. Dietz, 'Before the age of capital,' pp. 106-107.

systems took centre stage. Blaming the 'evil' excise system, the top eighteen manufacturers, at a meeting in Manchester, resolved that 'the destructive system [of taxation] adopted towards the manufacturers of this kingdom, and to this town and neighbourhood in particular, renders it incumbent upon them immediately to appoint delegates to go to Ireland for the purpose of treating with any public body, or individual, nobleman or gentleman, respecting a proper situation for conducting an extensive cotton manufacture'. The threat worked. On 20 April 1785, Pitt told the Commons that the new excise on plain cottons and fustians would be repealed.[25]

The rapidly growing power of the newer industries, most notably cotton, iron and pottery, was particularly evident in the 1786 trade treaty with France. This deal split British manufacturers roughly in half. Those older industries, used to protection, relatively monopolistic conditions and the excise, generally opposed the treaty. Newer industries that did not benefit from these conditions tended to support the treaty. As the pro-monopoly organ *The British Merchant* claimed in 1787, one group was keen to conserve control over the domestic markets, while the other faction sought 'an open trade' since 'their present ascendancy of skill, [has] nothing immediate to fear from competition, and everything to hope from the speculation of an increased demand'. The publication identified cotton, pottery and iron as representative of this latter group. Other industries, such as the silk, ribbon, hat, paper, clock and watch, leather and glass producers, believed that they would lose their domestic markets to the French. One woollen draper in 1786 foresaw the collapse of the old industries, claiming that if the iron, potteries and cotton manufacturers knew 'they rise by our fall, they would to a man scorn the notion of getting on by any such means'. Spearheading the negotiations with the French was William Eden. He had fervently opposed the excise on cotton and Pitt's favourable Irish resolutions, and was generally an important supporter of the new industries. In the negotiations, Pitt made it clear to Eden that he was willing to make concessions on glass and other products in order to aid cotton, some woollens, hardware and earthenware.[26]

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[25] Will Bowden, 'The influence of the manufacturers,' pp. 666-72, and Idem., *Industrial society*, pp. 172-175.

[26] Will Bowden, 'The English manufacturers and the Commercial Treaty of 1786 with France', *American historical review* 25 (1919): 18-35, on pp. 22-24, 29-35; Vivian E. Dietz, 'Before the age of capital,' pp. 178-180 and p. 186. For the French perspective on the treaty see M. Donaghay, 'Calonne and the Anglo-French Treaty of 1786,' *Journal of modern history* 50 (1978): D1157-D1184 (supplement – issue 3), and especially 'The exchange of products of the soil and industrial goods in the Anglo-French Commercial Treaty of 1786,' *Journal of European economic history* 19 (1990): 377-401.

In many ways the treaty was predominantly about cotton, on which Eden secured a mere ten percent duty from France. This underlines an extremely significant departure in eighteenth-century British industrial policy, one gathering pace since the Seven Years War. The period of nurturing chiefly non-exporting industries was eroding; they were now being tightly squeezed due to fiscal demands – placing them beyond the wall of custom tariffs. Increased inland duties were also accompanied by a greater disciplining of gauging methods and the mode of assessment, fuelling a general frustration and dislike of the excise. Meanwhile, the new competitive export-led industries, most notably cotton, were left relatively untouched. This selective proto-laissez faire policy, of course, would not reach full fruition before the nineteenth century, but the intersection between the state and industry was clearly being restructured. As Aytoun deftly summarised in 1848: 'The truth is, that the whole scheme of free trade was erected and framed, not for the purpose of benefiting the manufacturers at the expense of the landed interest, but rather to get a monopoly of export for one or two of the leading manufacturers of the empire'.[27]

The excise, production and practical objectivity

Clearly, tariff protection and the excise played a pivotal role in Britain's industrialisation during the first half of the eighteenth century. The excise became the chief source of manufacturing knowledge for the government, advising it through the Treasury. Here the excise suggested levels at which to pitch tax, gave extensive details on the nature of production, liaised with men of science and manufacturers and engaged with issues of quality – since allowing the production of second-rate items simply stoked the illicit importation of superior goods, and in the long run could destroy the survival of an industry. Taxing a good frequently required it to be rendered visible both in regard to its ingredients and in the way it was produced, ultimately calling for attempts to regulate its qualities and for its site of production to be reconfigured to meet the excise's process of measurement.[28]

The first half of this essay has thus specified what can loosely be called Britain's eighteenth-century economic policy; the focus will now be on the more mundane and everyday aspects of how a critical part of this policy, the excise,

[27] William Aytoun is quoted in Anna Gambles, *Protection and politics,* on p. 207.
[28] This section draws upon my following work: "Between the trader and the public": British alcohol standards and proof of good governance,' *Technology and culture* 42 (2001): 27-50; *Customs and excise: trade, production and consumption in England 1640-1845* (Oxford: Oxford University Press, 2003), pp. 261-279; 'Practical objectivity'.

actually worked. For the purposes of this section we will focus on the tools and techniques used in attempting to objectify the space of production. My primary concern is not with the question of whether administrative developments informed philosophical techniques, values and criteria, or whether natural philosophy informed administration – clearly it was a two-way process. Instead, I shall address two questions: first, the problem of 'practical' objectivity (that is, 'good-enough' objectivity) versus philosophic objectivity; and secondly, the relationship between state stipulations of practical objectivity and the impact they had on manufacturing practices and techniques in the eighteenth century. There is no doubt that the imperative of effective and efficient administration dictated the parameters of objectivity, but for much of the eighteenth century the intersection between the state and industry was also a prime mover of inventiveness.[29]

In order to define and levy the production of home-produced goods, the excise turned to quantification, and to a particular notion of accuracy that tried to advertise claims to objectivity and equity in its gauging activities (Ill. 37). The constitution and stages of a taxed manufacture had to be defined and made clearly amenable to the excise method. As well as defining what ingredients manufactures could use, the excise also dictated what times they could begin production and, to a great extent, the site of manufacture's shape.

To ease the volatile relationship between producers and the excise required the development of new means of collection. The general unpopularity of the excise since its inception by Parliament to fight the king in the English Civil War made it vulnerable, which was perhaps one factor behind its particular bureaucratic structure and practices – in the words of Theodore Porter, 'the drive to supplant personal judgement by quantitative rules reflects weakness and vulnerability'.[30] However, in the case of the excise three features were far more important: the fact that such rules enabled regularisation across the country, thus making it appear equitable; an attempt to create and sustain a certain quality of product; and, crucially, the ease of administrative efficiency and policing.

Consider the impact of the excise on the early eighteenth-century fledgling spirit industry.[31] The distillery, claimed the excise authority and well-

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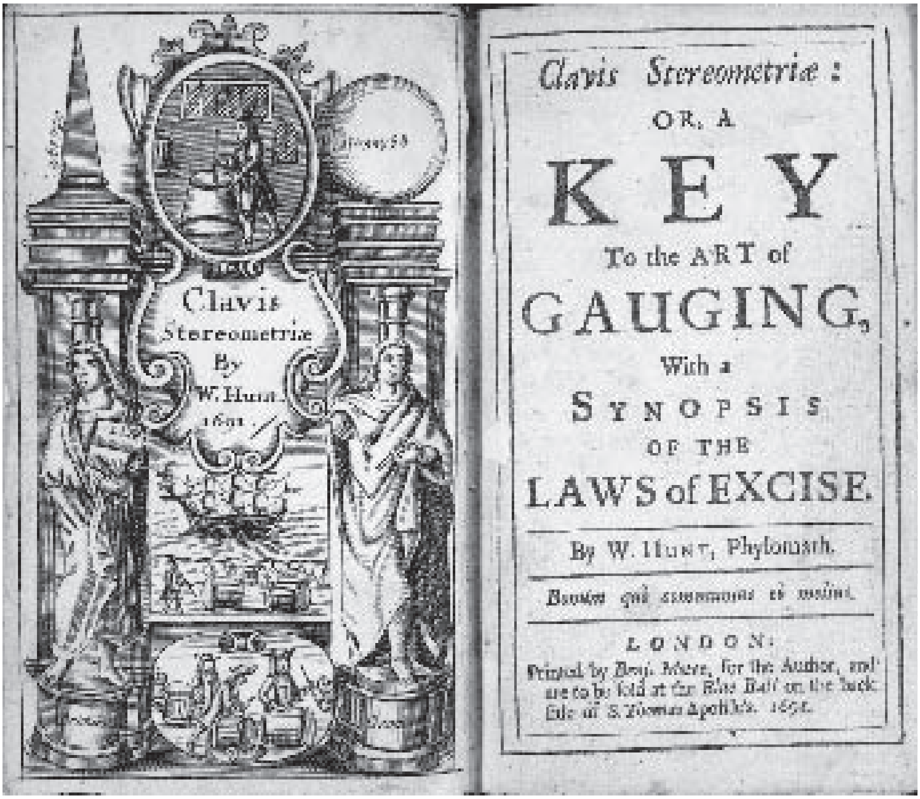
[29] For a similar process within twentieth-century accountancy see Michael Power, 'From the science of accounts to the financial accountability of science,' *Science in context* 7 (1994): 355-87, on pp. 357-360, and *The audit society: rituals of verification*, (Oxford: Oxford University Press, 1997).

[30] Theodore M. Porter, *Trust in numbers: the pursuit of objectivity in science and public life* (Princeton: Princeton University Press, 1995), p. ix, p. xi, pp. 194-196, 214, 221.

[31] For other examples see William Ashworth, *Customs and excise*, pp. 209-257.



Ill. 37. The frontispiece of a gauging manual, which illustrates the increasing importance of technical measurement in extracting revenue from trade. W. Hunt, *Clavis Stereometry or, A key to the art of gauging with a synopsis of the laws of excise* (London, 1691). Courtesy of the National Museums and Galleries on Merseyside.

known astronomer Charles Leadbetter, 'is the very *Apex*, or highest Pitch that can be aimed at by man in Gauging; for it is not only required that he should be very expert in *Gauging*, but also in the manner of Book-keeping, and making up the Accoumpts; which is more difficult than any other Branch of this Art'. Thus, between 1690 and 1784 the spirits tax was levied in two ways. First, a tax was put on the product after first distillation (low wines), and, secondly, on the final product (spirits).[32] In 1698 it was ruled that a distiller had one month to demolish any concealed vessels, pipes, stop-cocks or holes in the Wash-Back, and any secret warehouses. If he did not, and was caught, the

[32] Charles Leadbetter, *The Royal Gauger; Or, Gauging made Easy, As it is actually practised by the Officers of His Majesty's Revenue of Excise* (London, 1739, 2nd edn., 1743), pp. 179-181.

producer would be fined £100. In 1699, it was discovered that any quantity of wash made of molasses would, upon distillation, produce a quarter part of the same quantity into low wines or spirits of the first extraction, and two thirds of the quantity of the same low wines or spirits into proof spirits, or spirits of the second extraction. And since it had been found that distillers concealed large quantities of these low wines and spirits before the gauger had charged duty, officers were ordered to keep an account of all molasses wash found in the hands of any distiller. If they found any decrease, they were to charge the distiller for the same amount of low wines of the first extraction (a quarter part); spirits of the second extraction were charged at two thirds of the rate for low wines or spirits of the first extraction. A similar move was made in 1705 regarding the quantity of wash made of drink fermented from excised malted grain.

As with all excise products, the officer had to map the distillery by drawing and describing every conceivable detail, from the position of the various utensils to the positions, lengths and directions of the vast array of pipes. To aid the excise in this latter task, the pipe carrying wort or wash had to be red; that carrying low wines or feints had to be blue; while spirits had to be pumped along white pipes and water through black ones. This strict set of procedures again reveals the extent to which the excise went in organising the space of the distillery. If the officer suspected any distiller of evading these regulations, he was allowed – night or day – to break up the ground and walls of the distillery and search for illicit pipes. If any were found, the manufacturer was to be fined £100, while if he charged his still without notifying the excise he would also be fined £100. An additional fine of £50 was available if the producer used more than one quarter of wheat to two quarters of other grain for distillation. And the list goes on – a hefty £100 could be given if the distiller used 'any molasses, honey etc. in preparing wash for distribution'.[33]

The excise's technique of gathering revenue became gradually more fearsome over the course of the eighteenth century. The officer surveying calico printers was told to measure the actual distance between his home and the printers, in order to gauge the time it would take him to get there. He was to 'keep a Dimension or White Book at each Printers', for the taking an immediate Account of all Goods as they are received from the Drapers or others, entering the Name of each Proprietor, a progressive Number; with the Lengths and Breadths of all the Silks, Silk-Handkerchiefs, Calicoes, and Linens, under their respective Titles, as fast as they are measured'. On surveying a printer's

[33] Act of 6 Geo. IV.c.80, sect. 32 and 43; Samuel Locke, *A New Abstract of the Excise Statutes: Including the whole of the late regulations, to the end of the session of the 28 George III* (London, 1788), pp. 71-80.

workhouse or warehouse he had to take a note of the number of tables being used, the kind of goods being printed, and then 'take the exact Length and Breadth of every Piece of every Kind, and in a frame prepared for that Purpose, fairly to imprint the Length upon each Piece of Calico, and also the Breadth, if over or under the Statute, on the End thereof'.[34]

The officer was also strongly advised to make 'quick Returns, on your Traders, at Times unexpected' – to check, for instance, that the printer was not using inferior 'false Colours'. To do this he could normally tell by the preparation of the cloth, by the intensity of the colour, or by actually tasting the cloth. Even more important was an officer's ability to be able to distinguish different types of cloth. For instance, calicoes were primarily cotton, while those made of linen warp and cotton woof or shoot were known as 'cottons'. The former are looser, rougher, and characterised by a more woolly texture than flax, of which the warp and woof of linens are constituted. Thus the officer was expected to examine the warp in several places, which if found to be hard, smooth and strong would be classified as linen or cottons.[35]

Textiles such as the above, along with British-produced 'cambrics' (fine white linen originally made in the Low Countries) and 'lawns' (fine linen or cotton, originally made in France), were marked at each end by an excise stamp. If they were found 'without a mark at each end of every entire piece, or at one end of every remnant, they are forfeited, and may be seized and lodged in a custom-house warehouse or excise office: – after condemnation to be sold to the best bidder'. For such a crime the manufacturer would be fined £200, while a fine of £100 would be levied, coupled with two hours in the pillory, if the owner tried to bribe an officer to mark the textiles without payment of tax. However, the worst crime a manufacturer could commit would be to counterfeit the excise seal – this was 'deemed felony, without benefit of clergy'. A similar set of regulations surrounded printed silks and linens and, again, if any used a counterfeit stamp they would 'suffer death as felons'.[36]

The excise legislation for candlemakers specified that 30.28 cubic inches was contained in 1 lb. of dry tallow; for soap producers the figure was 27.14 cubic inches for hard soap and 25.56 for soft soap. In the case of glass, 8.46 cubic inches was allowed per 1 lb. of flint glass, 9.18 for crown and broad glass, and 10.18 for green or bottle glass.[37] The excise also ruled that a

[34] *Instructions for Officers who survey Printers of Callicoe, &c* (London, 1777), pp. 5-7.
[35] Ibid., pp. 12-14.
[36] Samuel Locke, *A New Abstract*, pp. 42-43 and for printed silks and linens see pp. 153-155.
[37] Henry Mackay, Supervisor of Excise, *An Abridgement of the Excise-Laws, and of the Custom-Laws therewith connected, now in force in Great Britain* (Edinburgh, 1779), pp. 42-43.

good tallow candle 'must be half sheep's tallow, and half bullock's,' while the manufacture of common candles had to be either moulded or dipped. A manufacturer had to pay an annual license and varying duties depending upon the quality of the candle. As well as making a detailed map of all the candlemaker's utensils and the layout of the workhouse and storehouse, the excise officer had the power 'to have entrance on demand, between five in the morning and eleven at night, with or without a constable' (during the night a constable was required). Before production could commence, the chandler had to inform the excise officer, and provide precise details 'of mould, size, and number of times he intends to fill the same'. If he did not he would be fined £50, while if he manufactured candles in a secret location he would be fined £100. The maker also had to supply robust fastenings to furnaces, coppers, pans and other utensils that he was not allowed to use without informing the excise officer – if he failed to comply and was caught, he would be fined £100.[38]

The pattern was similar for all excised manufactures. For example, the officer was allowed at all times ('if by night in the presence of a constable') to enter a paper-maker's premises. He was expected to make a note of all the rags and other materials found there. A ream of paper was to consist of twenty quires, and each quire to be of twenty-four sheets, while a bundle of paper was to have forty quires. If a ream or bundle did not match this requirement the producer would be fined £50. To confirm the legality of the paper the officer would stamp it. If the producer used a counterfeit stamp he would be fined a crippling £500.[39] The instructions did not stop here: all the paper had to be tied and wrapped in an elaborate and defined way, and the excise officer could at any time open a ream or bundle of paper to check that it was the quality specified.[40]

Soap manufacturers were strictly forbidden to 'set up, alter, or make use of any boiling-house, work-house, warehouse, &c. for making, or keeping sope, nor use any copper, kettle, fat, &c. without first giving notice thereof in writing at the next office'. If caught breaking any of these rules, the manufacturer would be fined £50. Again, producers had to supply locks and covers for all their utensils, while soap frames had to be two inches thick and not above forty-five inches in length or fifteen inches or more in breadth. If the manufacturer was found illegally manufacturing soap, he would be fined £100 and have all the produce seized. Waste from the manufacturing process, including

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[38] Anthony Highmore, *A Practical Arrangement of the Laws relative to the excise* (London, 1796), 2 vols., vol. 2, pp. 66-68; Locke, *A New Abstract of the Excise Statutes*, pp. 45-50.

[39] Ibid., 146-149.

[40] Anthony Highmore, *A Practical Arrangement of the Laws*, pp. 246-249.

the question of what constituted waste, was an ongoing problem in soap-making and glass production. Soap-makers were allowed one pound in ten as compensation for waste. If the manufacturer was suspected of using illicit pipes the excise officer, as in the case of spirits and beer, was allowed to smash up the manufacturer's floor (all pipes had to be above ground). If found guilty of illicitly siphoning lees or soap, the producer would be fined £50. The actual tax was charged by weight; additionally, hard soap had to be made into cakes or bars.[41]

A similar set of exhaustive stipulations faced the glass-maker. Again, as with all taxed manufactures, the space of production had to be totally mapped. If any pots, furnaces or warehouses were used without prior permission, the producer would be fined £50. Officers were allowed to enter the manufacturer's premises day or night, 'and inspect, examine, weigh, gauge, or otherwise take account of the metal and materials there mixed and prepared for making glass'. In addition, all the glass being made had to be gauged to 'take account of the capacity or content of each pot there found for making glass, and mark and number each pot as they think fit; and any person counterfeiting or altering any such mark or procuring or conniving thereat, shall forfeit 200 l.'.[42]

Legally defining the space of production and the manufacturing process only served to create new fraudulent activities, which then went on to inform new revenue legislation. In other words, legal 'framing' led to unpredicted 'externalities' that led to reframing.[43] Nonetheless, the process worked well enough during the eighteenth century to gather adequate revenue, and ensure that the state had enough credit to sustain the huge national debt; the ability to sustain Public Credit at such a magnitude made Britain unique in Europe. The success of the excise was particularly due to its eventual achievement in taxing goods at the point of production and encouraging, if not monopolies, then certainly larger and fewer producers preferably combining in a particular region. This made revenue collection cheaper through a more efficient use and allocation of employees, created greater consensus among manufacturers about the equitable nature of gauging techniques and increased specialisation among excise officers. Through its technical emphasis, coupled with crucial support from the legislature, protectionist policies and the army, the excise overcame rival calculative agencies and so enabled the boundaries of excise extraction to be stable enough to sustain its revenue generating capability.

41 Ibid, pp. 268-269; Locke, *A New Abstract of the Excise Statutes*, pp. 181-187.

42 Anthony Highmore, *A Practical Arrangement of the Laws*, pp. 116-126.

43 Michel Callon, 'An essay on framing and overflowing: economic externalities revisited by sociology,' Michel Callon, ed., *The laws of the markets* (Oxford: Blackwell, 1998), pp. 244-269.

By the nineteenth century, taxed manufactures had largely given up offering alternative means of gauging their products, and concentrated on ways of defeating state-defined methods. However, in doing so they had also accepted the form of state gauging as the official process of calculating the duty. (Analogously, once a weekly wage was established at the expense of perquisites and certain gratuities at ports and sites of manufacture, employees' subversion or negotiation hinged on the wage rather than custom.) In the case of excise collection, the state had done just enough to define the official boundaries – to frame the physical space and process of revenue collection. Of course, illegal revenue sapping deviations remained that had to be continually renegotiated. Nonetheless, for a substantial period the markets for excised goods were organised by and subject to broadly the same form of standard calculation using the same instrumentation. For example, by the mid-nineteenth century merchants and distillers on the whole agreed to the form of measuring adopted for taking the alcohol density of spirits on which duty was charged. It was through the hydrometer that the object of measurement was linked to the state, the importer and the distiller. (A form of the hydrometer was used up until the 1970s.)

The system had taken a long time to establish, and entailed extensive negotiation over methods of gauging spirits. In particular, it centred upon the relative merits of mechanized measurement and personal judgment. In an attempt to assuage the hostility of manufacturers and merchants, the eighteenth-century excise increasingly spearheaded developments in quantifying measurement and in inscribing the process within an instrument.

A diverse array of customary practices used to assess spirits created a difficult and often confrontational environment. Prior to the emergence of an instrument to measure alcohol content, people relied on various other tests. One of the oldest of these dated from the fifteenth century and worked by the addition of oil of a certain density to the liquor. The analysis was simple: if the spirit was strong, the oil sank; if it was weak, the oil floated. Another early method of finding 'proof' involved pouring some spirit onto a little gunpowder and then igniting it: if at the end of the combustion the powder went off with a little explosion, the spirit was held to be proof; if it burnt steadily, it was classed above proof. Perhaps the most popular and speedy technique was to shake the spirit in a glass vial and note the number of beads that formed at the edges of the surface, as well as the speed at which the beads formed and the length of time they remained. This was known as the 'bead,' 'crown' or 'proof vial' test, and it remained a customary test among importers and distillers throughout the eighteenth century.[44]

[44] F. G. H. Tate, *Alcoholometry: an account of the British method of alcoholic strength determination* (London: HMSO, 1930), p. xi; P. W. Hammond and Harold Egan, *Weighed in the balance: a history of*

However, even by the early eighteenth century the expansion and importance of the spirit duties made such methods appear too arbitrary. Distillers, merchants and excise officers frequently clashed in their estimation of a spirit's strength. It had been known for some time that the density (specific gravity) of spirits – that is, the ratio of the weight of the spirits to the weight of water – provided the most precise measure of alcohol content: a given volume of spirits weighed less than the same volume of water by an amount proportional to the strength of the spirits. The problem was finding a way to measure density to everybody's satisfaction. It was within this environment that excise officers turned to the London instrument and engine maker John Clarke, and encouraged him to make them a hydrometer.

Although Clarke's hydrometer found widespread use by the excisemen, and gradually by reluctant distillers and grumbling merchants, it was not mentioned in the Revenue Act of 1758. However, perhaps because of the sudden increase in new varieties of hydrometers and subsequent variations in results, Clarke's hydrometer was mentioned officially for the first time in an Act of 1762 that decreed that the standard gallon of spirits would be one composed of six parts by weight of spirits and one of water and weighing 7 pounds, 13 ounces at 50 degrees Fahrenheit. Clarke's hydrometer nonetheless faced a growing challenge to its credibility by merchants, distillers and rival instrument makers. Increasing objections to the instrument readings obtained by excise officers, coupled with the widespread use of techniques designed to defeat the instrument, placed the Board of Excise under pressure to resolve the situation.

The discontent of distillers and merchants was triggered by allegations that the latter deliberately adulterated brandy with molasses or other saccharine substances in order to evade the excise. It was far from clear whether these 'sweets' were in fact intrinsic elements of brandy – certainly many merchants thought they were. The issue became particularly controversial in 1760, when a series of experiments suggested that a method had been devised to disguise the strength of brandy by infusing it with treacle or syrup, which Clarke's hydrometer failed to detect – the hydrometer could accurately determine the alcohol content of a liquid only as long as the solution did not contain anything that would affect its specific gravity. In response, it was decided that if an exciseman suspected a brandy that tested underproof of having been deliberately sweetened as a means of preventing 'the fair and proper gauge being taken of its strength or experiment made to ascertain the strength of it,' he

the laboratory of the government chemist (London: HMSO, 1992); George Smith, *Something to declare: one thousand years of customs and excise* (London, 1980), p. 81.

was to charge double duty without regard to the actual measurement of proof. This temporarily had the desired effect of eliminating the practice – or, one might also argue, of altering the constitution of popular brandy to ensure that it conformed to the limitations of the hydrometer.[45] But in 1780 the custom of sweetening brandy revived. The price of spirits had shot up in 1778 as the government desperately sought new ways to fund the spiralling costs of the American War of Independence, and the practice of adulterating spirits intensified, according to one nineteenth-century historian of taxation, to 'the utmost point possible'.[46] In this context the efficacy of the hydrometer was severely tested.

This situation has to be understood in relation to the general tax crisis of the 1780s discussed in an earlier section. The matter came to a head in December 1781, in *The King vs. Steele and others*. The case ostensibly concerned the Crown's allegation that Steele and Company, London-based spirit merchants, had sweetened their imported brandy in order to avoid paying double duty. But as the trial progressed it became increasingly clear that the credibility of the Board of Excise itself and its reliance upon Clarke's hydrometer were in the dock. Most distillers and merchants still relied on customary standards based on the human senses, and many saw these as superior methods of gauging actual strength; they used the hydrometer reluctantly, and only because the revenue department had adopted it. In practice, the court case concerned the following issue: was the judgment of excise officers being bent toward the interests of the state, or had the brandy indeed been sweetened to such a degree as to constitute a deliberate evasion of the duty? The trial exposed the fragile foundations that underlay the supposedly objective measurement obtained through the use of Clarke's hydrometer. In the broadest sense, *The King vs. Steele and others* concerned the state's ability to define and police the character and quality of goods, an ability on which the extent and security of the state's revenue implicitly depended.[47]

The trial highlighted the problems of ambiguity and objectivity surrounding Clarke's hydrometer. The issue of adulterated spirits had merely triggered

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[45] *The King v. Steele and others*, 4 Dec. 1781, National Records, CUST 103/3, 240-1.

[46] Stephen Dowell, *A history of taxation and taxes in* England, 4 vols. (New York: A. M. Kelly reprint, 3rd edn., 1888, 1965), vol. 2, p. 172.

[47] It is interesting to compare the different trajectory of the beer hydrometer (the Saccharometer) at the intersection of the brewer and excise, see James Sumner, 'John Richardson, saccharometry and the pounds-per-barrel extract: the construction of a quantity,' *British journal for history science* 34 (2001): 255-273, and especially his 'The metric tun: standardisation, quantification and industrialisation in the British brewing industry, 1760-1830' (unpublished PhD, University of Leeds, 2004).

the real question, namely, that concerning the diverse array of techniques still used in the trade to ascertain spirit strength. Traditional tests that relied on senses of sight, smell and taste increasingly had no place in the bureaucratic apparatus of excise collection. Equally intolerable were the different interpretations of Clarke's hydrometer made by distillers and traders, a problem compounded by the array of rival instruments. What was needed was a universal standard, defined by an arbitrary density, made to yield to a standardized hydrometer, and with the final result presented as a number.

The problem of adulterated brandy quickly found a solution: in 1786, William Pitt's administration raised the duty on the sweets added to spirits and beer. In the following year Clarke's hydrometer (not variants on his instrument) was legally sanctioned as the standard. However, the statute also recognized the problematic nature of the instrument and therefore invited Britain's premier scientific society, the Royal Society, to investigate the most effective means of establishing the duty to be paid on a liquid containing spirits. But it was not until the Act of Union between Britain and Ireland, in 1802, that any urgent action was taken oven the inadequacies of Clarke's hydrometer. The newly appointed supervisor and assayer at the port of Dublin, William Speer, produced a detailed and devastating report for the treasury documenting the limitations of Clarke's instrument.[48]

A committee of the Royal Society was once again duly established, and a competition launched to build a new hydrometer. The committee members included the eminent chemist and experimental philosopher William Henry Wollaston; William Farish of Cambridge University; the inspector of imports (excise) for the Port of London, Thomas Groves (the exciseman who had accused Steele and Company of adulterating spirits in 1781) and the secretary of the Royal Society, William Mandell. Others involved in the experiments included John Grant, Surveyor of Excise for Scotland; the instrument maker Thomas Sanders; the chemist William Higgins (nephew of one of the Crown's expert witnesses in *The King vs. Steele and others*); a distiller at Battersea, one Mr. Bennell and other 'persons of trade'.[49]

Despite a popular call to change the definition of 'proof' from Clarke's hydrometer proof to proof spirit, the committee decided to retain the former as the standard, probably for the reasons that Jessie Ramsden had earlier outlined in 1792:

[48] W. Speer, *An Inquiry into the Causes of the Errors and Irregularities which Take Place in Ascertaining the Strengths of Spirituous Liquours by the Hydrometer* (London, 1802).

[49] F.G.H. Tate, *Alcoholometry*, p. 5

> [T]o retain the present value of Proof, will, no doubt, have many advantages: it will prevent that confusion which always happens in commerce, when any change of the value, or denomination, of merchandise takes place. I would therefore progress to ascertain what is the specific gravity of the Proof by Clarke's Hydrometer, or as it was fixed (by the weight per gallon,) and make that specific gravity the term. [50]

Greater precision, in other words, was desirable to the extent that it did not cause too much disruption to established commercial practice. In the end, the committee declared Bartholomew Sikes's hydrometer the winner of the competition (Sikes had been the state's main expert witness at the 1781 trial), since it best combined ease of use and acceptable precision, that is, practical objectivity.

Of course, greater precision did not mean that the new hydrometer was any better at detecting substances deliberately (or carelessly) added to spirits to defeat it. The Act therefore also decreed that spirits designed 'to defeat the Operation of the said Hydrometer' would be seized. Although placing high duties on sweets had helped stem the practice of adulterating brandy, the technical problem of measuring adulterated spirits remained unresolved; Friedrich (or 'Fredrick') Accum, one-time chemical assistant at the Royal Institution and director of a major London gas-lighting company, was to discuss the continuing adulteration of spirits in his *Treatise on adulteration of food, and culinary poisons* (London, 1820).[51]

Imitation through adulteration

This essay has argued that protectionary tariffs and the approach of the excise played an important role in informing the development of British industrialization. Another important factor, as the recent work of Berg has shown, was the attempt to imitate foreign goods (and, in the process, change them), which also led to new innovative production processes. This lesson was not lost on the common economy. Indeed, the entrepreneurial spirit was rife in this alternative market.

Since the second half of the eighteenth century, the space between the consumer and the producer of food and drink had become much greater. There had always been periodic public complaints over the quality of flour, bread and beer, and such complaints increased in frequency in the second half

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[50] Jessie Ramsden, *An Account of Experiments, to Determine the specific Gravity's of Fluids, Therby to obtain the Strength of Spirituous Liquors by the Hydrometer* (London, 1792), p. 25.

[51] For more on Accum, see Simon Werrett's essay in this volume.

of the century; but they were as nothing compared to the rage expelled in the nineteenth century. By this point, as John Burnett writes in his important work on food adulteration, 'an ever-increasing proportion of the population was necessarily dependent on others for its food, and, as capitalisation and specialisation advanced, more and more separated from the ultimate food-producers: in the process, the old local relationships and sanctions which had existed between consumers and retailers largely broke down'.[52] Many people clearly embraced rather than opposed the fruits of early capitalism. The expansion of mass-produced necessities also provided the state with a larger foundation of revenue to harvest. Jan de Vries's 'industrious revolution' served the interests of the state as much as it did the manufacture benefiting from such greater consumption.[53] This, in turn, further induced manufacturers to adulterate their products; from its initial role of helping to nurture quality, by the close of the century the excise was fuelling adulteration – although, ironically, the revenue bodies were also the only possible source of protection for the consumer. Their first line of duty, however, was to safeguard the state's coffers and not the people's health. The consumer was seemingly digesting cheaper and frequently poisonous substances at ever-greater levels.

The public concern over the adulteration of tea was fed by a number of well-publicised excise trials against manufacturers and sellers during the 1810s. This led to more sophisticated forms of testing tea, and to the emergence of a new set of tea dealers who played on the increasing public fear of adulteration. In 1819, almost 100 people were prosecuted for adding such dangerous substances as cocculus indicus, multua, capsicum, copperas, quassia and numerous other things to beer. All these ingredients were cheap alternatives to expensive excised malt and hops, and provided the appearance of strength and flavour.

Within the context of late-eighteenth century Britain, public health and food adulteration simply were not mainstream government (or public) concerns. For one thing, the knowledge and instrumentation for detecting adulterants was simply lacking, as was medical understanding of the harmful effects of such adulterants on people's health. Adulterants became a widely discussed problem chiefly due to government fears that it was losing a great deal of revenue. From about the mid-1810s the excise started utilising the

[52] John Burnett, 'The history of adulteration in Great Britain in the nineteenth century, with special reference to bread, tea and beer' (unpublished PhD thesis, London School of Economics, 1958), pp. 8-9, 19.
[53] For the industrious revolution see Jan de Vries, 'Between purchasing power and the world of goods: understanding the household economy in early modern Europe,' John Brewer and Roy Porter, eds., *Consumption and the World of Goods* (London: Routledge, 1993), pp. 85-132.

argument of public health in its various prosecutions. Of course, it only did so in an attempt to win cases and safeguard the revenue, and it was this latter consideration that brought the issue into the public sphere. By 1855, according to the founder of *The Lancet*, Dr Arthur Hill Hassall, adulteration of spirits was costing the revenue £2,196,000, of malt £2,040,000, of tobacco £908,000, and of wine, hops, tea, and sugar each between a third and a quarter of a million pounds. It was also the case that many people had come to prefer the taste of adulterated goods.[54]

Accum's book of 1820 was the first widely read and regarded study on the subject (see illustration 36 at the front) Inspired by the recent spate of excise prosecutions against manufacturers for adulteration, Accum set out to investigate its extent. Such practices were big business, dominated by a number of large organisations that defeated 'the scrutiny of the revenue officer'. The whole process was carefully organised 'to ensure the secrecy of these mysteries, the processes are very ingeniously divided and sub-divided among individual operators, and the manufacture is purposely carried on in separate establishments'. Accum then proceeded to give literally hundreds of ways by which various commodities were adulterated. For example, coculus indicus (a poisonous berry), known in the market as 'black extract' and meant for the use of leather tanners and textile dyers, was more often added to highly excised porter or ales. A substance composed of an extract of quassia and liquorice juice was used to stretch the use of malt and hops.[55] Wine was one of the most adulterated of taxed commodities: the colour of new wines was made brighter by adding alum, Brazil wood or the husks of elderberries and bilberries in order to deepen the colour of pale red port, while gypsum was used to make cloudy white wine transparent. 'Wine-brewers' were costing the country a great deal of lost revenue.[56]

Other taxed and heavily adulterated products included tea, coffee and spirits. An imaginative creation promoted by Edmund Rhodes of Hatton Garden eventually cost him a fine of £500. He was found dyeing, fabricating and manufacturing hundredweight lots of sloe leaves, ash leaves, elder leaves and various other leaves, to be used in imitation of tea. Another group of men received convictions for employing a small army to pluck leaves from North London bushes as a major adulterant for tea: the leaves were first converted to resemble black tea by boiling them, baking them upon an iron plate, and then rubbing them with the hands to make them recoil into the distinctive curl of black

[54] John Burnett, 'The history of adulteration,' pp. 21-7, 33-41 and 344-48.

[55] F. Accum, *A Treatise on Adulterations*, pp. 5-8, 5-8 and 153-67.

[56] Quoted in ibid., pp. 98-99.

tea (the colour was given by the addition of logwood). To make green tea, the leaves were laid upon sheets of copper, where they received their colour with the help of a substance called Dutch pink. The operation was completed by adding the deadly poison verdigris. Those involved in this particular case were fined £840.[57]

A typical defence by grocers of adulterated coffee was to plead that they were in some way providing a public service to the poor. This had proved to be a successful tactic during the Napoleonic wars, but quickly lost its effectiveness following their conclusion. Take the case of Edward Fox, a dealer in tea and coffee convicted in 1818: 'he did it as a matter of accommodation to the poor, who could not give a higher price; he did not sell it for genuine coffee'. The judge hearing the case had no time for such arguments, concluding: 'Then you have been defrauding the public for many years, and injuring the revenue by your illicit practices: the poor have an equal right to be supplied with as genuine an article as the rich'. The same verdict awaited the tea and coffee dealer Alexander Brady in 1818.[58]

As we have already seen in the case of brandy, one tactic the excise used in compensating for adulteration was to tax the main adulterant. Thus, from 1832 grocers were permitted to keep chicory on their premises, and eight years later to sell it mixed with coffee. In 1851 more so-called coffee, made primarily of chicory, was being sold, while far less-taxed coffee was being imported. As far as the government was concerned this was not a major problem, since home-grown chicory had been highly taxed since 1840. Even here, however, the erstwhile adulterant was in turn adulterated. A grocer from Shoreditch revealed a compound of burnt peas, dog biscuit, prepared earth 'and a substance which I shall not describe because it is too horrid to mention,' used instead of chicory (several tons were in fact offered). The bottom line, as Burnett points out, was revenue and not health: 'With the purity of food and drink as a whole, the excise had no concern whatever; its interest was entirely fiscal, and it seems not improbable that the Treasury would have sanctioned an adulteration if its effect had been to increase, rather than diminish, the revenue'. In fact, as we have just seen, the Treasury did just this.[59]

Perhaps the most significant fiscal development of the 1840s, along with the introduction of the Income Tax and the eclipse of the Corn Laws, was the establishment of the first state laboratory in October 1842. It was headed

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57 Ibid., pp. 224-33.

58 Ibid., pp. 243-53 and John Burnett, *Plenty and want: a social history of diet in England from 1815 to the present day* (Aylesbury, 1968), p. 106.

59 John Burnett, 'The history of adulteration', pp. 58-60.

by an excise employee, George Phillips, and aimed to scrutinise excisable goods (originally only tobacco, but soon also the remaining excised items, primarily beer, wine, spirits, tea, coffee and sugar) for adulteration. The tobacco trade was initially sceptical that adulteration, with up to five percent sugar, could be detected, and they continued to add it to their tobacco. However, Phillips on his personal visits to large sites of manufactures brought many successful prosecutions in the first year of the Act. By 1844, something like 30,000 lbs. of tobacco had been seized in Lancashire and Yorkshire alone.[60]

Conclusion

Through its distinct approach to taxing various manufactures, the excise played both a direct and an indirect role in defining the process of production and, at least to begin with, in helping to nurture backward manufacturers. This, combined with a protective wall of customs tariffs, played a fundamental role in British industrialization. By setting a standard method and approach to gauging, it was clearly hoped that controversy could be deflated – by both appearing equitable in taxation and having a set procedure to which to appeal. This form of practical objectivity served three purposes: first, that of providing just enough objectivity to appear just; second, the provision of a way of policing quality (until the tax reached such a level that it intensified illegal practices and nurtured adulteration instead); and third, the standardisation and rationalisation of excise practices: a taxed good would be measured in exactly the same way throughout Britain.

Ultimately, as with Michael Power's analysis of accounting practice in the twentieth century, the excise's use of objectivity was an 'administrative rather than an ontological product'.[61] England's leading man of science, William Wollaston, knew this when he replied to a question concerning Sikes's new system of gauging spirits. For all of his input and praise of Sikes's instrument, he also wanted to make it quite clear to the excise Commissioners that, unlike himself, Sikes was no philosopher, and that the instrument was therefore not theoretically sound. 'Altho' I have above proposed the completion of Sikes's Hydrometer according to his own principles, which appear sufficiently correct for all practical purposes, I wish it at the same time to be distinctly understood by the Board that I do not consider them to be philosophically accurate'. Wollaston did not want his name associated with Sikes's hydrometer if the princi-

[60] P.W. Hammond and Harold Egan, *Weighed in the balance*, pp. 8-22 and 71-4.
[61] Michael Power, 'From the science of accounts,' p. 362.

ples underpinning the instrument were published. If this was to be the case, 'it might be advisable to give a perfect theory, & to make certain small alterations of the weights, And it would then also become necessary to revise the tables & to make corresponding small corrections, which under the present circumstances do not appear worth the trouble they would occasion'. The instrument, as far as Wollaston was concerned, was ready as long as its claim to objectivity was not associated with him – it was no product of a new or exact science.[62]

This essay has argued that more important than some unique, indigenous culture of rationality fuelling British industrial development was the institutional context. The nature of excise regulation entailed close control of manufacturers while also attempting to elevate their products – and these two facets were anything but mutually exclusive. The eventual method and form of gauging established a correlation between the product, its quality and the revenue demands of the state. In this way, the excise worked as a kind of mediator between producer and state, stirring contention but also permitting compromise. Practical objectivity clearly acted as an important force for change in manufacturing, a force that worked within a complicated fiscal-mercantile-military institutional matrix, and which played a prominent part in eighteenth-century British industrialization. However, by the 1780s the intersection between the state and industry was under severe strain, and would be dismantled over the course of the next century.

Primary sources

Anon., 'The Influence of Free Trade upon the Condition of the Labouring Classes,' *British Edinburgh Magazine* 27 1(830): 553-68.

Dowell, Stephen, *A History of Taxation and Taxes in* England, 4 vols. (London: Longmans, 1884, 3rd edn., 1888, New York: A. M. Kelly reprint, 1965), vol. 2.

Highmore, Anthony, *A Practical Arrangement of the Laws relative to the excise* (London, 1796), 2 vols., vol. 2.

Instructions for Officers who survey Printers of Callico &c (London, 1777).

Leadbetter, Charles, *The Royal Gauger; Or, Gauging made Easy, As it is actually practised by the Officers of His Majesty's Revenue of Excise* (London, 1739, 2nd edition., 1743).

Locke, Samuel, *A New Abstract of the Excise Statutes: Including the whole of the late regulations, to the end of the session of the 28 George III*, London, 1788.

Mackay, Henry, *An Abridgement of the Excise-Laws, and of the Custom-Laws therewith connected, now in force in Great Britain* (Edinburgh, 1779).

Parnell, Henry, *On Financial Reform* (London, 3rd edition., 1831).

62 Wollaston is quoted in William Ashworth, 'Between the trader and the public,' p. 48.

Ramsden, Jessie, *An Account of Experiments, to Determine the specific Gravity's of Fluids, Therby to obtain the Strength of Spirituous Liquors by the Hydrometer* (London, 1792).
Robinson, David, 'The Silk Trade,' *Blackwood's Edinburgh Magazine* 18 (1825): 736-50.
Speer, W., *An Inquiry into the Causes of the Errors and Irregularities which Take Place in Ascertaining the Strengths of Spirituous Liquours by the Hydrometer* (London, 1802).
The Crown v. William Savage, 12 July 1802, National Records, CUST 103/51.
The King v. Steele and others, 4 Dec. 1781, National Records, CUST 103/3, 240-1.

Mapping the movement of men and machines in papermaking

ILLUSTRATION 38

Becoming competitive: England's papermaking apprenticeship, 1700-1800

Leonard N. Rosenband

In 1761, the astronomer and technical writer Joseph-Jérôme Lefrançois de Lalande observed that paper had become an 'everyday merchandise'.[1] The rise of the novel, the rants of Grub Street and fashionable wallpaper, among many enticements, all fed this swelling demand. So did the eighteenth-century state's expanding desire to count, regulate, explain and hence document. But the purchase of paper was no everyday affair. This was an epistolary era, when 'friends and neighbors' greeted and assailed each other with 'little notes, invitations to dinner, thank-you notes, begging notes, scolding notes, and notes for no reason at all'.[2] The medium itself was a critical part of the message, since the firmness and hue of the paper spoke volumes about rank and the worth of a relationship. Consumers cautiously evaluated the stationery and the properties of the paper in the books they purchased – books that were sold as masses of unbound, folded, cut and carefully sewn sheets. They rubbed the paper between their fingers and hoisted it up to the light for a clear look at its knit, colour and blemishes. They shared an arcane vocabulary of quality, chattered about the paper's *force* and *oeil* (roughly, 'lustre'), and went into rapture about the azure tint of Dutch reams. Not every producer reached the scribblers' and printers' standards; indeed, even in the relatively advanced mills of Holland and France, many turned out lacklustre wares. Still, it was a telling sign that English and Welsh papermakers were said to be much improved by 1782, when about 480,000 of the 900,000 reams they furnished were brown or whited-brown, that is, coarse paper.[3]

A half-century ago, David Landes termed the industrial transformation of France, Belgium and Germany 'Continental emulation', and there was no

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[1] Joseph-Jérôme Lefrançois de Lalande, *The art of papermaking*, trans. Richard Atkinson (Kilmurry, Ireland: Ashling Press, 1976), p. 56. Lalande originally published his *Art de faire le papier* in 1761.

[2] Edmund Morgan, *The Genuine article: a historian looks at early America* (New York: Norton, 2004), pp. 169-170.

[3] Richard Hills, *Papermaking in Britain, 1488-1988: a short history* (London: Athlone Press, 1988), p. 53.

doubt about the location of the prime mover.[4] According to Eric Hobsbawm, 'Subsequent [industrial] revolutions could use the British experience, example and resources. Britain could use those of other countries only to a very limited and minor extent'.[5] R. M. Hartwell concurred: England's industrial ascension 'was a growth achieved mainly without external assistance'.[6] Moreover, Hartwell depicted the English industrial revolution as an exercise in 'balanced growth', a process that animated most sectors of production.[7] For all these scholars, a distinctive, self-generated approach to manufacture had retooled the instruments and nature of Britain's workshops. From Birmingham and like-minded precincts, English migrants, machines and wares moved abroad, challenging moss-covered manufacture wherever they landed. What returned, at least in the form of men and tools, had far less impact.

Accounting for this precocious British 'take-off' has provoked intense debate and generated a veritable catalogue of explanations. These include accessible seams of coal and iron ore, a progressive agriculture that freed labourers for urban and industrial employment, a lively consumer revolution, a blue-water naval policy and the muscular mastery of colonial markets, Protestant Dissenters attuned to fresh opportunities in commerce and production, a native inventiveness and an aptitude for refining foreign inventions profitably, an early application of science (or scientific methods and principles) to manufacture, the integration and specialisation of domestic markets and a government bent on import substitution. This roster, and a host of other elements, inspired Landes's, Hartwell's and Hobsbawm's confidence in the primacy and self-fashioned essence of English industrialisation. Here, too, were the features that framed Peter Mathias's answer to his famous query: Was British industrial development first because it was unique, or unique because it was first? He replied in the affirmative to both dimensions of the problem. After all, he reasoned, Britain had engineered the original industrial pathway. Followers might seek to duplicate the journey or craft their own route, but the territory would never again be uncharted.[8] This mapping, however, does not trace

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4 The quoted phrase is the title of chapter three of David Landes, *The unbound Prometheus: technological change and industrial development in western Europe from 1750 to the present* (Cambridge: Cambridge University Press, 1969), p. 124.

5 Eric Hobsbawm, *Industry and empire: from 1750 to the present day*, revised and updated with Chris Wrigley (New York: New Press, 1999), p. 13. Perhaps the most ambitious and persuasive recent study of industrialising Britain is M. J. Daunton, *Progress and poverty: an economic and social history of Britain, 1700-1850* (Oxford: Oxford University Press, 1995).

6 R. M. Hartwell, *The causes of the Industrial Revolution in England* (London: Methuen, 1967), p. 3.

7 Ibid., p. 15.

8 Peter Mathias, *The transformation of England: essays in the economic and social history of England in the eighteenth century* (New York: Columbia University Press, 1979), pp. 3-20, esp. 3 and 20.

the course of eighteenth-century British papermaking. In many ways, this trade was distinctive because it was second, a position it overcame, in part, by emulating the Continental art and then surpassing it – if this lead can be measured solely by the gadgets England's papermakers came to possess.

In 1747, one R. Campbell assessed the condition of English papermaking in *The London Tradesman*:

> We are but lately come into the Method of making tolerable Paper; we were formerly supplied with that Commodity from France, Holland and Genoa, and still are obliged to these Countries for our best Papers….The French excel us in Writing Paper and the Genoese in Printing Paper, from whom we take annually a great many Thousand Pounds worth of that Commodity.

Campbell's report cuts across the grain of our assumptions about nascent industrial Europe. It is his sense of the persistent vulnerability of the English trade that is most striking, its merely 'tolerable' reams coupled with the import of 'a great many Thousand Pounds' of superior sheets from several Continental sources. Still, Campbell also observed, rightly, that the English trade was improving.[9]

This essay explores the 'inventive intersections' that accounted for the progress Campbell detected and the gains that would follow. In doing so, it emphasises the transnational, circular roots of seemingly linear technical and commercial growth. More precisely, it considers the shifts in British handicraft papermaking as a Dutch device and the 'French interest took footing' in the island's mills.[10] Indeed, British papermaking entered the craft's transnational mainstream, unsteadily to be sure, by naturalising the workaday as well as the inventive aspects of Continental papermaking's technique, fashion and instruments. Accordingly, this study considers the portability of practice and the porosity of political borders in the age of manufactures. Yet, it is not a conventional inquiry into industrial convergence, the narrowing of international technological and shopfloor distinctions. Rather than shrinking this process to the transfer, or imposition, of a set of techniques and tools from one (national) production site to another, it considers the restless generation of hybrid workshops. Instead of the imitation of all things British, convergence, at least in European papermaking, yoked together Mediterranean stamping hammers, Dutch rag cutters, English wove moulds and the fingertip practice of diverse skilled men, as well as tastes and styles set in the paper markets of Paris,

[9] Quoted in D. C. Coleman, *The British paper industry, 1495-1860: a study in industrial growth* (Oxford: Clarendon Press, 1958), p. 92.
[10] Quoted in A. H. Shorter, *Paper making in the British Isles: an historical and geographical study* (New York: Barnes and Noble, 1972), p. 27.

Amsterdam and Hamburg. As James Cutbush described this process in the contemporary American trade, the papermakers 'have the advantage of the experience and emigration of all the foreigners, the several different modes of work have been brought over, and the practice we have adopted seems to have arisen out of a fair comparison of them all'.[11] Thus Bryan Donkin's refinement of the French papermaking machine in an experimental shop in Bermondsey, which doomed the handicraft, was one of a series of reciprocities in a trade with deep, transnational wellsprings. Rather than locate his labour wholly in an English industrial revolution, this paper situates it in the wider evolution of the sector. And it suggests that the reason of state as well as shopfloor empiricism must be linked to the 'industrial Enlightenment,' even as England became the workshop of the world.[12]

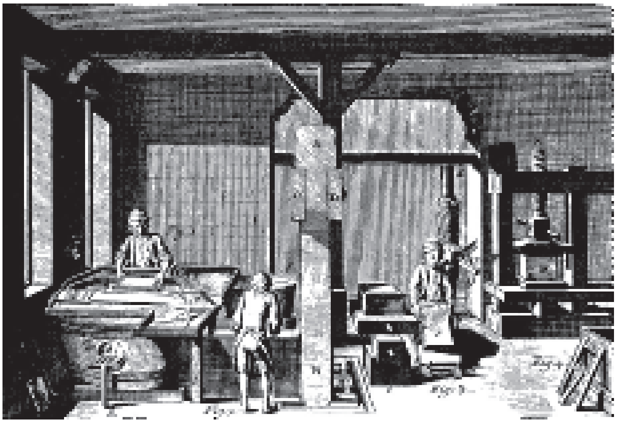
As evidence of an Elizabethan industrial revolution, John Nef turned to a poem about the works and days of John Spilman, a German who had established a paper mill in Kent. The poet Thomas Churchyard claimed that 'Six hundred men, are set a worke by [Spilman]'.[13] More likely, the figure was less than twenty. Judging by his complaint that the 'Petitioner is forced to make browne paper' due to the scarcity of discarded linen, the raw material of his art, Spilman likely faced overwhelming competition from abroad.[14] But the division of labour and basic manipulations of his craft would have been familiar in mills on either side of the Channel. Effectively, hand papermaking consisted of three stages: the rotting and mechanical reduction of castoff linen into pulp, the creation of the sheet and the preparation of the newly minted paper for ink and shipment. Female hands began the production process. They divided white rags from grey, removed caked dirt, and cut away matted patches. Experienced men watched over rows of stamping mallets that separated the linen, already weakened by a period of fermentation, into cellulose filaments. The vatman evaluated the colour and consistency of this material, the surest guide to the final weight of the ream. Then he dipped his mould, a rectangular wire mesh bounded by a wooden frame, into a tub filled with the warm, watery pulp. He quickly lifted the mould and shook it in a customary pattern so that the fibres of the infant sheet 'shut'. (He performed this task 4000 times each day.) Finally, the vatman passed the mould, with a fresh sheet clinging to it,

[11] *Early American papermaking: two treatises on manufacturing techniques reprinted from James Cutbush's American artist's manual (1814)* with an introduction by John Bidwell (New Castle, Del.: Oak Knoll Books, 1990), p. 73.

[12] On the 'industrial Enlightenment', see Joel Mokyr, *The gifts of Athena: historical origins of the knowledge economy* (Princeton: Princeton University Press, 2002).

[13] Quoted in Dard Hunter, *Papermaking: the history and technique of an ancient craft* (New York: Dover Publications, 2d. ed., 1947; reprint, 1978), p. 120.

[14] Quoted in D. C. Coleman, *British paper industry*, (cit. n. 9), p. 48.



Ill. 39. The vatcrew: *Receuil des planches, sur les sciences, les art libéraux, et les art méchaniques, avec leur explication*, 4e livraison: tome 22, Papetterie' , planche 10: 'Cuve à Ouvrer' [papermaking vat] (Paris: chez Briasson, David & Le Breton, 1767).

to the coucher. This craftsman's main tool was a stack of hairy felts, which he rested on a small easel. He needed steady hands and good timing, since he flipped six or seven sheets of paper per minute from wire to felt. Once his pile of felts, each bearing a moist sheet of paper, reached the customary height, it was pressed. The layman then separated the paper from the felts, a delicate task, Lalande claimed, 'suitable only for people who have practised it from an early age and not for uneducated, inexperienced country-folk'.[15] More pressing followed and the sheets were draped over cords to dry. The sizerman gathered this paper and immersed it in an emulsion of hides, hoofs, tripe, and alum. This gelatine bath filled the paper's pores, thereby preventing ink blots. The sizerman tested his work with his tongue: if it left a balanced impression that resembled a fan or a butterfly's wing on the sheet, the finish was proper. Finally, women sorted the paper, excised stained and clotted swatches, and assisted the loftsman in wrapping the reams. Rich in lore and marked by a durable division of labour, this process took weeks to turn discarded linen into paper.

About a century after Churchyard's verse, *The British Merchant* reported that 'the Manufacture of White Paper is almost entirely new in this Kingdom' and that 'before the Revolution there was hardly any other paper made in England than brown'.[16] In 1685, John Briscoe secured a royal patent 'for

[15] J. J. Lalande, *Art of papermaking*, p. 41.
[16] Quoted in D.C. Coleman, *British paper industry*, p. 55.

making English paper…as white as any French or Dutch paper'.[17] But it was not to be: at the turn of the century, the informed Charles Davenant lamented 'we are not come up to the French perfection' in the production of paper.[18] Small wonder that William Petty, in an undated estimate, observed that England was in debt to France for 'Papers of all Sorts w^{ch} are made at Auvergne, Poictou, Limosin Champaigne and Normandy for about 100000£ p an'.[19] Just before Christmas 1697, the Commissioners for Trade and Plantations chimed in: 'We humbly conceive it is also a very usefull Manufacture deserving all incouragement, and that we may improve to make as good as what comes from abroad'. Like Davenant, these officials centred on the scarcity of castoff linen – 'the want of white Raggs' – as 'a great hindrance to the progress' of the trade. They also proposed 'for the Incouragement' of the craft 'that all paper imported ought to pay a higher Duty than Paper made at home'.[20]

Drawing a sharp line between foreign policy, revenue policy and industrial policy, especially the pursuit of import substitution, obscures the intentions of England's governors regarding papermaking. Above all, they wanted receipts from home markets supplied by domestic products. Just behind this goal was the exclusion of French reams. The protection of England's immature papermaking industry took several forms. In 1686, the king bestowed a patent on the newly formed Company of White Paper Makers. Here was the French 'footing' in the home trade: the Company's founding petitioners included Adam de Cardonell, Nicholas Dupin, Elias de Gruchée, James de May, Marin Regnault and Robert Shales. The incorporation of this fledgling monopoly in July 1686 confirmed its sole right to produce stationery and printing paper in England for fourteen years.[21] The Company's heyday lasted only through the early 1690s; but its bitter exchanges with rival papermakers reveal much about the condition of the English craft at the close of the century. The monopolists mocked their competitors' claims that they furnished a sizeable quantity of printing paper. Even with the finest discarded linen at their disposal, the Company's unfortunate adversaries could turn out nothing better than reams destined for the wrapping of gloves, thread and tobacco. Another group, the Paper-Traders, joined the chorus: they contended that the monopolists' rivals – the remainder of England's papermakers – produced only brown and

17 Quoted in ibid., p. 69.
18 Quoted in ibid., p. 53.
19 William Petty, 'A Catalogue of French comodities yearely transported into England,' n.d., Papers of William Petty, British Library, Add. MSS. 72,890.
20 Commissioners for Trade and Plantations, 'Paper Manufact^{r},' 23 Dec. 1697, British Library, Sloane MSS. 2902.
21 A.H. Shorter, *Paper making*, p. 24.

coarse white papers. The Company's enemies retorted that these favored manufacturers were more successful at kiting the value of their stock than fashioning fine reams. But A. H. Shorter, the distinguished historian of the British art, listed the fleeting monopoly's contributions to English papermaking as 'the great care it gave to the preparation of materials, the use of improved equipment for the manufacture of the better sorts of white paper, and the practice of superior skills'.[22]

To protect England's lucrative paper markets and the kingdom's hundred or so small mills in 1700, the state enacted a variety of measures. Consider the ratio between the customs and excise duties Parliament prescribed in 1711. A foreign ream known in the trade as fine demy – if it did not originate in the Auvergne or Normandy – suffered a levy of 4s.; the excise burden on its domestic counterpart was 1s. 6d. On fine foolscap, the relative weight of the imposts was 2s. 6d. and 1s. And so it went, except that the importer was also charged a set of earlier ad valorem duties: the Old Subsidy, the New Subsidy, the One-Third Subsidy and the Two-Thirds Subsidy.[23] The English manufacturers who petitioned Parliament in the years 1710-1712 understood precisely why these elevated barriers were necessary: they did not wish 'to lose the Benefit of all our Arts and Endeavours therein, after so many years Labour and Industry, and at such vast Costs and Charge, when we have arrived to equal Knowledge with Foreigners, in that Trade'. Bravado aside, the papermakers concluded that a favourable tariff-excise ratio was essential 'that so useful a Manufactory may not be lost to the Nation, and Thousands of People lie starving for want of Employ'.[24] In 1714, Parliament raised the levy on both imported and home-produced reams by 50 percent. Then pressure on the Treasury yielded a 'subsidy' of 5 percent on foreign paper in 1748 and a second in 1759, another impost of 5 percent of the *total* of all the previous levies in 1779, and a fresh hike of 5 percent on the new total in 1782.[25]

Meanwhile, the importers of French goods faced considerably stiffer tariffs. In 1692, Parliament affixed a duty of 25 percent of the paper's value in the Book of Rates to French reams. Four years later, a new measure added a second impost of 25 percent to constrain the trader in papers from Champagne and the Limousin.[26] Throughout the eighteenth century, French paper

[22] Ibid., p. 25.
[23] H. Dagnall, *The taxation of paper in Great Britain, 1643-1861: a history and documentation* (Queensbury: In collaboration with The British Association of Paper Historians, 1998), pp. 12-13, Tables 2 and 3.
[24] Quoted in A.H. Shorter, *Paper making* (cit. n. 10), p. 44.
[25] H. Dagnall, *Taxation*, p. 22, Table 5.
[26] Ibid. These duties applied to a variety of commodities.

entered Britain at a premium. 'An Account of the Duties on Foreign Paper imported,' likely the handiwork of a late eighteenth-century scrivener, carefully separated the duties for each sort of paper into two columns: 'French' and 'not French'. The difference between the rates bulked large: fine French foolscap bore a tariff of 8s. 4 13/20d. per ream, while the equivalent paper from Voltri or the Zaan region carried a charge of 6s. 1 18/20d.[27] Evidently, this premium took its toll on the importation of French wares. According to one compilation, the average annual value of the Italian paper that made its way to English shores from 1770 to 1784 was £2563, a figure ten times greater than that for French reams.[28] But this table made no mention of smuggling nor of the ease that Dutch producers had in putting their watermarks in paper fashioned in Angoumois. The Dutch mill owners there had long fancied this deception to avoid the prohibitive tariff on the export of their reams to London.

Certainly, English manufacturers were securing a larger portion of the home market for paper. In an unwarranted burst of enthusiasm, Parliament in 1722 decided that the output of Britain's mills was sufficient to satisfy domestic needs. Consequently, the lawmakers removed the export duties on paper.[29] But some old problems remained. During the debates surrounding the Act of 1711, the papermakers lamented that '[i]t is true Foreigners have the advantage of Materials'.[30] Mr. Torriano was more specific in a speech before the House of Lords on 8 June 1713. He worried that '[t]he common people in France are naturally industrious, their clothing cheap, their nourishment mean, so that they can, and do, work much cheaper than ours....They have flax and lyne of their own for their linen manufacture, this also affords them materials for their paper'.[31] Parliament failed to intervene on the wage issue, but in 1725, 'for the Encouragement of the making of Paper in this Kingdom,' the lawmakers permitted the duty-free entrance (so long as a record of their arrival was kept at the Customs house) of 'old Rags, old Ropes or Junks, or fishing nets, fit only for making pasteboard or paper'.[32] This policy persisted until 1803. Yet, despite the rise of the Irish and Scottish linen industries, substantial imports from the Continent, and the mid-century efflorescence of English production, which coincided with the displacement of

[27] 'An Account of the Duties on Foreign Paper imported,' n.d., British Library, Add. MSS. 38,387.
[28] 'Average Importation of Foreign Paper for 15 Years from 1770 to 1784,' n.d., British Library, Add. MSS. 38,345.
[29] H. Dagnall, *Taxation*, p. 20.
[30] Quoted in A.H. Shorter, *Paper making*, p. 44.
[31] Nathaniel [?] Torriano, Speech in the House of Lords, *Manuscripts of the House of Lords*, vol. 10, new series, 1712-1714 (London, 1953), p. 132.
[32] Quoted in D.C. Coleman, *British paper industry*, p. 106.

linen by sugar as Britain's largest single import, access to cheap, plentiful heaps of rags troubled England's papermakers throughout the century.[33]

Protected markets and spiralling demand, however, did not inevitably generate improved English reams and practices. According to the Commissioners of Inquiry into the Excise Establishment, deft Continental craftsmen had contributed much to the advance of the English art. In 1835, they recounted that 'it was owing…to the want of skill…that the manufacture of paper was not carried on with much success in England till a comparatively recent period…. The manufacture is said to have been considerably improved by the French refugees who fled to this country in 1685'.[34] Even before the revocation of the Edict of Nantes, French papermaking expertise had landed in Scotland. In 1675, the proprietor of the Dalry mill employed 'sevinten Scotsmen and boyes bred up and instructed in these airts be [by] the french'.[35] A dozen years later, a concerned French state threatened those émigrés who found work in foreign paper mills with the galleys, 'even if they profess the Catholic faith'.[36] Soon after, the controller general alerted his agent in Limoges that 'it is important to support papermaking and if possible to prevent the migration of its workmen to England'.[37] Meanwhile, England's early quality producers searched abroad for skilled hands: Daniel Roussillon, a French exile in Southampton, journeyed to Gelderland in 1688 in pursuit of dextrous paperworkers.[38] Apparently, much of Protestant Europe benefited from the flight of Huguenot paper manufacturers and journeymen. In 1708, French officials twice confirmed that Huguenot producers in Holland had matched 'only too well' the better grades of French paper.[39] And Thomas Hearne observed a decade later that 'much the best Printing Paper in England is made at Southampton, by a Frenchman' – almost certainly Roussillon.[40]

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33 On linen imports from the Continent, see David Ormrod, *The rise of commercial empires: England and the Netherlands in the age of mercantilism, 1650-1770* (Cambridge: Cambridge University Press, 2003), pp. 141-180. For the Irish and Scottish industries as well as a wide range of Continental producers, see Brenda Collins and Philip Ollerenshaw, eds., *The European linen industry in historical perspective* (Oxford: Oxford University Press, 2003). On the displacement of linen by sugar, see Niall Ferguson, *Empire: the rise and demise of the British world order and the lessons for global power* (New York: Basic Books, 2003), p. 14.

34 *Fourteenth Report of the Commissioners of Inquiry into the Excise Establishment* (London, 1835), Appendix 1, p. 45.

35 Quoted in D.C. Coleman, *British paper industry*, p. 78.

36 Henri Gazel, *Les anciens ouvriers papetiers d'Auvergne* (Clermont-Ferrand: A. Dumont, 1910), p. 105.

37 Quoted in Warren Scoville, *The persecution of Huguenots and French economic development, 1680-1720* (Berkeley and Los Angeles: University of California Press, 1960), p. 234.

38 A.H. Shorter, *Paper making*, p. 24.

39 Quoted in Warren Scoville, *Persecution* (cit. n. 37), p. 346.

40 A.H. Shorter, *Paper making*, p. 52.

Soon the ground shifted, however, and the Dutch became the model for the enterprising papermaker. In the 1730s and 1740s, two progressive Irish producers resolved to construct 'a new Mill after the best Dutch Manner'.[41] Behind this project was a device, the Hollander beater, a handful of related instruments, some manual turns and the delicate blue tint of Dutch stationery. For the most part, it was said, Dutch paper mills were somewhat larger and better capitalised than their French counterparts. Lacking the force of mountain streams, they depended on wind to drive their stamping hammers. But the sea breezes often failed to move the banks of mallets; worse, prolonged calm turned vatfuls of rotting rags into waste. So Dutch manufacturers worked with fresh linen and trusted the shredding to a new device, the Hollander beater. Perfected in the 1670s, an oval tub served as the frame for this machine. A metal or stone box, studded with knives, was fixed to the tub's floor and a horizontal cylinder, again armed with blades, rotated over the stationary bedplate. As wind or water turned the cylinder, the rags were drawn through a gauntlet of opposed metal and separated into filaments.

Dispensing with fermentation saved time, water and money – less linen was lost and more ended up as the substance of sheets. Two Hollander beaters did the work of eighty mallets, and required less space and supervision.[42] The machines worked quickly, taking no more than one-third of the time needed by the stamping hammers.[43] They also conserved resources, since breakage in the course of manufacture amounted to a quarter of the losses suffered by French *fabricants*.[44] The firm uniformity of Dutch paper entranced consumers and invigorated producers; simply put, the papermakers of Holland enjoyed considerable advantages of cost and, particularly in the lucrative stationery market, quality.

The secret of the handsome surface of Dutch paper lay in a technique known as *échange*. Whereas French manufacturers regulated the air flow in their drying lofts to hasten evaporation, the Dutch conserved the dampness of their fresh sheets. They pressed their wares lightly, shuffling the packs of paper between each turn of the screw. Successive contact with new sheets flattened the rough spots in each and preserved a gentle grain. To match the velvet shimmer of Dutch goods, the French beat their sheets with trip hammers and burnished them with smoothstones. Nevertheless, the grain of French paper, so important in guiding the pen and determining the product's worth, remained less regular.

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41 Quoted in D.C. Coleman, *British paper industry*, pp. 110-111.

42 Nicolas Desmarest, 'Papier (Art de fabriquer le),' in *Encyclopédie méthodique: Arts et métiers mécaniques,* vol. 5 (Paris, 1788), p. 495.

43 J.J. Lalande, *Art of papermaking*), p. 28.

44 Nicolas Desmarest, 'Papier', p. 522.

Yet, the Dutch device, known in England as an 'engine,' was not without drawbacks: 'English Raggs being cut by Engines, make the Fibres so short, tho' coarse…and makes the Paper of a harder nature'. French paper, the Royal Society of Arts learned, continued to be 'softer and the fitter for [copper-plate] Printing,' indeed for printing in general.[45] The machine also took time to master: at first, English 'engineers' tended to drive it too rapidly, flinging pulp in every direction.[46] But English papermakers gradually learned the knack, and the device diffused across the trade during the second half of the eighteenth century. Here was a textbook case of Gerschenkronian advantage, the advantage of the latecomer.[47] Whereas the relatively refined French industry adapted slowly to the Hollander beaters, the still maturing British trade was considerably more open to them. And persistent protection of the home market reduced the risk of introducing these devices in the island's workshops.

As late as 1738, the Commissioners of Excise affirmed that at least three-quarters of England's mills still furnished coarse reams.[48] Equally, Thomas Balston, a well-versed chronicler, maintained that '[t]ill the outbreak of war with Spain in 1739 little good white paper was being made in England, and stationers and publishers relied almost entirely on importations from the Continent'.[49] But men, machines and even reams from the other shoulder of the Channel had left their mark on the English trade; and wartime embargoes and sheltered growth permitted it to edge closer to the main currents of Continental practice. Disruptions in commerce with Europe during the War of the Austrian Succession cemented the position of English producers in the home market for fine stationery and printing, and the spread of Hollander beaters in the ensuing years firmed this footing.[50] Taken together, this appears to be a straightforward tale of industrial convergence, albeit with the geographic poles reversed. But the Dutch protected their rag trade more consistently than their paper markets and French papermakers in the Auvergne and Normandy shunned Hollander beaters.[51] In a sense, then, English papermaking

[45] Quoted in D. C. Coleman, 'Premiums for paper: the Society and the early paper industry,' *Journal of the Royal Society of Arts* 107 (1959): 361-365, on p. 362.

[46] Richard Hills, *Papermaking in Britain* (cit. n. 3), p. 58.

[47] Alexander Gerschenkron, *Economic backwardness in historical perspective: a book of essays* (Cambridge, Mass.: Belknap Press, 1962), esp. ch. 1.

[48] Quoted in D.C. Coleman, *British paper industry* (cit. n. 9), p. 91.

[49] Thomas Balston, *James Whatman, father and son* (London: Methuen, 1957), p. 12.

[50] Hills, *Papermaking in Britain*, p. 67.

[51] On the Dutch, see Charles Wilson, *Anglo-Dutch commerce and finance in the eighteenth century* (Cambridge: Cambridge University Press, 1941), p. 21; and Dick van Lente, 'Innovation in paper making: The Netherlands, 1750-1850,' *History and technology* 14 (1998): 201-224, on p. 205. As Van Lente observes, 'the Dutch government protected the paper makers by prohibiting the import of paper in

was self-fashioned, but not in the mode outlined by Landes, Hartwell and Hobsbawm. It was a distinctive work-in-progress cobbled together from Huguenot know-how, a device designed to overcome the physical constraints on Dutch production and carefully fenced markets. It was not the forerunner's uniqueness that had mattered, but a long time also-ran's striving to catch up and compete.

From his elevated perch in English papermaking, the younger James Whatman was unimpressed with the outcome of all this exertion. In 1764, he instructed the Commissioners of Excise that 'the rivalship of the Dutch (who can already undersell us) makes it necessary that we should afford ours at a Foreign Market as cheap as possible'. But, he fumed, 'at least half the Paper that is made [in England] pays no Duty at all'. Even worse, 'almost the whole Burthen falls on People of Credit,' the visible producers of quality wares, such as Whatman himself. As a result, his papers faced still another hurdle in international markets. To end his fellow producers' successful evasions, he believed '[i]t will be absolutely necessary to put the Makers Name as well as the true Name of the Paper in each Sheet'. Honestly marked, every ream – and its manufacturer – would bear its fair portion of the excise duty. And the paper itself would improve: Whatman celebrated '[t]he almost certainty of the Manufacture being brought to a still greater degree of perfection by the Emulation between the Makers when their Names are in their Papers'.[52]

Properly marked paper, with it origins and quality transparent to all, would flush frauds from Whatman's art and impel healthy 'emulation' in the market. Here were the benefits of precisely governed information, the sure foundation of improved, market-worthy goods. How French. Except that Nicolas Desmarest, an inspector of manufactures across the Channel, trusted in a private ordering of papermaking that 'should dispense the government from fixing any other arrangement'. Formats and watermarks would be determined by sustained use in the marketplace and conserved in 'the steady relation' of consumer and producer as well as the always slow 'revolutions of carefully considered needs'.[53] So it was in English papermaking, where printers, stationers and

times of overproduction, which happened occasionally'. For the absence of Hollander beaters in Normandy and the Auvergne, see Louis André, *Machines à papier: innovation et transformations de l'industrie papetière en France, 1798-1860* (Paris: Éditions de l'école des hautes études en sciences sociales, 1996), p. 58.

[52] James Whatman, 'Some Reasons that make it necessary to alter the present Method of levying the Excise on British made Paper,' 2 Dec. 1764, British Library, Add. MSS. 38,203.

[53] Quoted in Leonard Rosenband, 'Nicolas Desmarest and the transfer of technology in old regime France,' Karen Merrill, ed., *The modern worlds of business and industry: cultures, technology, labor* (Turnhout, Belgium: Brepols, 1998), p. 111.

manufacturers reached their own accords, hedged by custom, about the balance of 'perfect,' speckled and 'broken' sheets in a well-formed ream.

England's papermakers were connected by visible links as well as subterranean ties. In 1694, each manufacturer of playing cards had to cough up 10s. to defray the costs of lobbying for a repeal of the tax on their wares.[54] Having learned in 1710 about a bill 'for the better preventing Excessive and Immoderate Gaming,' the Company of Playing Card Makers quickly headed 'to the Parlt House to solicite the Company Business'.[55] Failing in an earlier bid to put an end to excise charges on their goods, the 'Paper Makers of Great Britain' petitioned the Treasury in 1765 'to recommend it to the Commissioners of Excise to collect the Duty on Paper for this year only with the same Lenity as has been done for many years past'.[56] By the end of the century, cabals of paper manufacturers halted work in their mills in desperate attempts to lower the cost of castoff linen and wages. Price-fixing, too, had its place in the papermakers' arsenal. Despite their lawyer's warnings about the illegality of their joint activities, the manufacturers were 'under the Idea, that as nobody would be injured by those measures that (they) could not conceive that any person would indict them and were therefore determined to run that risque'.[57] A shrewd petitioner to the Treasury in 1812, as well as a second six years later, plotted to introduce French reams into England under the reduced customs duties established for rags.[58] Both intended to remill the French goods and transform them into fresh sheets. To get around the French embargo on the export of linen sweepings, one of the importers certified that the cargo destined for England would be 'prepared in a certain way in France so as to insure the means of exporting it…in the shape of coarse Paper and Pasteboard'.[59] Transnational cunning, domestic cheek, lively lobbying and tightly knit, informal webs were all at play in English papermaking. These links and traits might speed the diffusion of Hollander beaters, but, as Whatman hinted darkly, they could also slow the 'Emulation' that favored best practice and quality production.

Improving Britain's speciality paper manufacture proved particularly difficult. In 1756, the Royal Society of Arts (RSA) offered a premium for copper-plate

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[54] John Brewer, *The sinews of power: war, money and the English state, 1688-1783* (Cambridge, Mass.: Harvard University Press, 1990), p. 237.

[55] Quoted in ibid., p. 238.

[56] 'Petition of the Paper Makers of Great Britain,' 1765, The National Archives (TNA): Public Record Office (PRO), CUST 48/17.

[57] Quoted in D.C. Coleman, *British paper industry* (cit. n. 9), p. 281.

[58] 'Memorial of Louis Fauche Borel,' 15 Aug. 1812, TNA: PRO, CUST 48/54; and 'Memorial of George Paine,' 11 Feb. 1818, TNA: PRO, CUST 48/73.

[59] 'Memorial of Louis Fauche Borel'.

engraving paper that equalled its French counterpart. The RSA championed import substitution through the duplication of foreign, particularly French, processes and products. Nevertheless, Maxine Berg believes the trials of imitation led to inventive procedures and goods.[60] Here shopfloor empiricism shaded into the principles of Encyclopedism, at least to the extent that the Royal Society of Arts rewarded experimentation and mandated reproducibility. In 1763 and again in 1764, Thomas Cooke of Tottenham Mill in Middlesex received rewards from the RSA for his copper-plate reams. Still, his technical virtuosity may have trailed French standards. Around 1770, Edward Wyburd bought the mill from Cooke and converted it to grind grain.[61] Meanwhile, in 1768, Robert Dossie provided a half-hearted endorsement of England's copper-plate papers: the prize 'for making this paper equal in all qualities to the French has never been yet obtained: though the Society's endeavours have procured the manufacture of an inferior kind, which answers for common purposes; and makes a national saving'.[62] In 1787, a Buckinghamshire manufacturer finally secured the gold medal, accompanied by the inevitable tributes. The minutes of the RSA reveal that its committee was 'of opinion that the premium should be no further extended'. But in the margin, to the side of this verdict, there was a brief entry: 'disagreed to'.[63] Making local practice cosmopolitan was trying, especially when cradle and competitors were one.

Making local practice national took time as well. Marbled paper entered the eighteenth century as something of a luxury and finished it as a widely accessible commodity. Testimony before the Court of Exchequer disclosed that '[f]ormerly all the paper used for the purposes for which marble paper is used was brought from Holland or from France but chiefly from Holland' – or from France in Dutch ream wrappers.[64] Once again, the RSA had offered a premium to stimulate home production, and once again had granted it. Most notably, the witnesses summoned by the Court were mindful of both the proper dimensions of the sheets *and* the proper procedures for their manufacture. 'Useful knowledge' had made it to the bar. Illicit reams continued to sell, but a national product and the specifications for its creation had taken shape through the interaction of the Royal Society of Arts, the machinery of the excise and the paper manufacturers.

60 Maxine Berg, 'From imitation to invention: creating commodities in eighteenth-century Britain,' *Economic history review* 55 (2002): 1-30.

61 A. H. Shorter, *Paper mills and paper makers in England, 1495-1800* (Hilversum: The Paper Publications Society, 1957), p. 213.

62 Robert Dossie, *Memoirs of Agriculture and Other Oeconomical Arts*, vol. 1 (London, 1768), p. 92.

63 *Minutes*, 3 April 1787, p. 168, Library of the Royal Society of Arts.

64 The Attorney General versus Thomas Wills, 1784, TNA: PRO, CUST 103/13, p. 73.

England's first advance in the technology of the trade came in 1756, when the elder James Whatman perfected wove paper. These sheets were largely free of the crosshatched tracings of most Old Regime paper. Manufacturers had long tried to hammer these marks out of their wares, but to no avail: the 'raying' of handmade paper was its birthmark. In wove paper, a fine brass screen, laced together on a loom, replaced the wires of a traditional mould. Rather than sharp impressions, the threaded brass left indistinct hints and sheets of a more uniform thickness. The virtues of wove paper were first visible in an edition of *Virgil* published by John Baskerville in 1757.[65] Tangled claims for French precedence in the manufacture of these sheets suggest that the paper had gained attention in Gallic markets. In 1784, the French Council of State declared that '[Jean-Baptiste] Réveillon [of wallpaper fame] has discovered the means to fabricate, at his paper mill in Courtalin, papers of an equal thickness throughout without trace of laid or rib lines'.[66] Certain English papers, then, had entered the era's broadened 'international circuits,' as Michael Sonenscher depicted them, 'of designs and designers, colours and chemicals, styles and fashions'.[67] Indeed, after 1774, the younger Whatman produced enormous sheets known as 'Antiquarian' that evidently captured Continental markets.[68]

In 1775, there were about 345 paper mills in England and Wales, and the total reached at least 417 in 1800.[69] The Royal Society of Arts declared in 1781 that the consumption of paper was 'every day encreasing'.[70] Still, British assessments of the home industry jockeyed between bluster and uncertainty, pride and frustration. England's paper hangers and manufacturers were loud, apprehensive opponents of the negotiations to lower Anglo-French trade barriers in 1786.[71] While sizing up the French and English goods that would prosper or suffer under this initiative, William Pitt cautioned that '[t]here are some other articles, such as hats, paper, leather, etc., on which it is perhaps doubtful which way the advantage would lie'.[72] Even Pitt's guarded prediction about the commerce in paper proved somewhat optimistic, but wartime trade restraints

65 On Whatman and wove paper, see Richard Hills, *Papermaking in Britain* (cit. n. 3), pp. 65-79.

66 Quoted in Leonard Rosenband, 'Jean-Baptiste Réveillon: a man on the make in old regime France,' *French historical studies* 20 (1997): 481-510, on p. 495.

67 Michael Sonenscher, *Work and wages: natural law, politics and the eighteenth-century French trades* (Cambridge: Cambridge University Press, 1989), p. 213.

68 A.H. Shorter, *Paper making*, p. 61.

69 Ibid., p. 76.

70 Quoted in D.C. Coleman, *British paper industry* (cit. n. 9), p. 171.

71 John Ehrman, *The British government and commercial negotiations with Europe, 1783-1793* (Cambridge: Cambridge University Press, 1962), p. 46, esp. n. 10.

72 Quoted in Ibid., p. 57.

closed this breach. By 1794, the claim circulated *in England* that Whatman's printing paper matched that of the enemy and was 'manufactured more neatly'.[73] Yet, a quartet of books published in Canterbury in 1777, 1778, 1782 and 1790 on the history of Kent, where Whatman's mill was located, was printed on imported reams.[74]

An exultant Matthias Koops, who had just received patents for his straw-based paper and for the extraction of ink from wastepaper, explained in 1800 that 'by perseverance, convenience in the construction of these manufactures, superior engines [Hollander beaters], presses and machines, and improved moulds, [England's] industrious [paper] manufacturers' had succeeded.[75] French visitors to Koops's short-lived mill marvelled that he had replaced the screw press with a hydraulic device, which 'has the advantage of not shaking the buildings when it is used'.[76] England possessed an 'actual pre-eminence' in his trade, Koops concluded, a lead that must not be jeopardised by, say, the printing of the particulars of his patent for straw paper.[77]

In the threatening circumstances of 1796, however, Koops's tune had different lyrics. Should the French secure the 'free navigation' of the Rhine and Scheldt, he feared they would 'monopolize the whole trade of almost all the northren part of Europe; and particularly to the exclusion of the trade and manufacturers of Great Britain'.[78] English papermaking faced wholesale risks, since '[p]aper manufactories have been long established in France, superior to the English'.[79] On balance, Koops probably had it right: England's papermaking instruments likely matched or even bettered those of their Continental rivals, while the skill and technique of the English craft may have lagged. Tools had failed to offset fully the advantages of touch, and price competition still troubled the British trade. Koops ascribed the French edge to an old *marron*, the 'cheapness of all the necessaries of life,' especially 'the low price of workmanship and manual labour' in France.[80] In fact, England's paperworkers pushed restlessly for higher wages and had organised a national trade union by the early nineteenth century. But Britain's paper manufacturers also faced a

73 Quoted in A.H. Shorter, *Paper making*, p. 60.

74 Richard Hills, *Papermaking in Britain*, p. 75.

75 Matthias Koops, *Historical Account of the Substances which Have Been Used to Describe Events, and to Convey Ideas, from the Earliest Date, to the Invention of Paper* (London, 1800), pp. 72-73.

76 Quoted in Dard Hunter, *Papermaking*, p. 201.

77 Matthias Koops, *Historical Account*, p. 73.

78 Matthias Koops, 'A developement of the views and designs of the French Nation…' (London, 1796). The quoted phrases are from the lengthy title itself.

79 Ibid., p. 201.

80 Ibid., p. 235.

state constantly searching for revenue as well as the soaring cost of frayed rope and discarded linen.

Pitt's hard-pressed regime raised the duties on imported paper in 1784 and simplified the cumbersome system of levies on foreign reams in 1787.[81] In 1781, 1782, 1784 and 1787, the state increased the excise as well. (These obligations were also consolidated in 1787.[82]) To put the 1781 measure in perspective, the younger Whatman chalked up 4 percent of his costs to the excise before the Act; by 1785, he was handing over 20 percent.[83] Not surprisingly, manufacturers, with the necessary complicity of printers, grocers and stationers, turned to a series of dodges, including home-made excise stamps, the reuse of previously stamped ream wrappers and the stuffing of reams with untaxed sheets. The producers took these risks despite the likelihood of hundreds of pounds in penalties if they were convicted: from 1778 to 1814, the Court of Exchequer held 59 trials of papermakers and stationers charged with fraud.[84] If 'Lenity' had once been the tone of collection, as the manufacturers proclaimed in 1765, that time had passed. For example, a Bristol excise officer refused to stamp some stained paper in 1787. The owners of these sheets had missed – by two days – the exemption granted for 'Old Stock' by the new Act. The collector then convinced the merchants to seek an allowance from the Board of Excise: 'They accordingly sent a Petition to the Board which in return has been pleased to send Orders to the Collector to instruct his Officers to search & make Seizure of all the Papers in the possession of the Petitioners not stamped as the Law directs'. The merchants eventually reclaimed their confiscated goods, but the excise had become the predatory mirror of protection.[85] In 1794, the excise officers' task was simplified, since the duty now rested on the weight of the reams rather than the myriad denominations used by manufacturers and stationers. As a result of the relentless rise in the excise on paper, the state's revenue from this tax climbed from £15,223 in 1772 to £166,301 in 1800.[86]

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[81] H. Dagnall, *Taxation*, pp. 23-24.

[82] D.C. Coleman, *British paper industry*, pp. 133 and 135, esp. n. 6. See also H. Dagnall, *Taxation*, pp. 24-33.

[83] T. Balston, *James Whatman*, p. 71, Table G.

[84] The number of trials and the list of fraudulent practices were drawn from TNA: PRO, CUST 103.

[85] This account of the events was drawn from TNA: PRO, CUST 48/22. The quoted passage is from 1 Feb. 1787.

[86] A.H. Shorter, *Paper making*, p. 45. Part of this increase, it should be noted, can be traced to the elimination of the ad valorem category by the Act of 1781, closing a loophole that had let much undervalued paper slip through. On this point, see D. C. Coleman, *British paper industry*, p. 133, and William J. Ashworth, *Customs and excise: trade, production, and consumption in England, 1640-1845* (Oxford: Oxford University Press, 2003), p. 251. In 1801, Pitt and the Parliament doubled the excise duty on paper. After intense protest, the excise duty on first-class paper was reduced by 40 percent in 1802.

Linen scraps consumed thirty to fifty percent of every papermaker's budget, depending on the quality of his reams. During the last decades of the eighteenth century, English producers furnished their vats with rags from sources extending from Iberia to Russia, as well as from transatlantic ports. But the pickings were increasingly costly and often slim – licit English and Welsh rag imports from 1776 through 1780 lagged behind those of 1771-1775 by almost 500 tons. English and Welsh ports handled about the same tonnage of castoff linen in the period 1796-1800 as they had during 1771-1775, but the hundredweight of fine rags that sold in England for 35 to 37s. in the 1780s fetched 58s. in 1804.[87] War with Napoleon and Parliament's reimposition of an import duty on rags in 1803 only added to the toll. Despite Koops's patent for his straw paper, D. C. Coleman concluded that the Continent witnessed the most notable of the pioneering inquiries into rag substitutes.[88] Bark, grass and leaves were the subjects of these tests, but in England esparto grass did not become a commercially successful stock until the 1860s and wood pulp awaited the 1880s. Meanwhile, to ease their burden, English papermakers again relied on an advance made elsewhere – the development of chlorine bleaching. Discovered by a Swedish apothecary and applied quickly to old ropes and stained linen, chlorine bought some time for Britain's papermakers, even if its bleaching properties were imperfectly understood. Improper use of this chemical rapidly reduced rags to rubbish. Even the younger Whatman, a tireless experimenter with the instruments and ingredients of his trade, '[d]oes not think highly of the bleaching'. He preferred to work with 'fine rags,'[89] so one early breakthrough of industrial chemistry apparently left no impression on his paper – the paper James Watt used for his engineering drawings in Birmingham.[90]

The rising price of skilled hands and their persistent scarcity also haunted England's manufacturers. During the 1680s, Denis Manes, a French refugee with two mills in or near Plymouth, was 'detained' for a number of years in his native land. According to Shorter, he had 'gone over to France to fetch more workmen for his mills'.[91] Several generations later, Manes's successors placed advertisements in newspapers for qualified tenants and journeymen. John Gater of South Stoneham sought 'a sober man who was 'capable of carrying

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[87] For the sources and amounts of rag imports, see D. C. Coleman, *British paper industry*, p. 107, Table 6. Coleman noted that Scottish imports constituted 'a very small percentage of the total' during the decade 1790-1800. For the price of fine rags, see, p. 173.

[88] Ibid., p. 171.

[89] Joshua Gilpin, quoted in T. Balston, *James Whatman*, p. 125.

[90] Richard Hills, 'James Watt and paper and papermaking,' Peter Bower, ed., *The Exeter papers: proceedings of the British association of paper historians, Fifth Annual Conference*, 2001, pp. 67-68.

[91] A.H. Shorter, *Paper Mills*, p. 159.

on the Business of Paper making'.'[92] In 1741, a Northumberland announcement claimed that three or four hands 'being good workmen in making brown paper might have immediate employment'. Journeymen skilled enough to fashion white reams 'would also be wanted later'.[93] With more urgency, a Gloucestershire papermaker pursued a man capable of 'undertaking a white vat' in 1743, reflecting the growing refinement of the English craft.[94] By 1795, William Turner, an Oxfordshire entrepreneur, wanted an engineer (for his Hollander beaters) and three skilled hands 'for white work'; a year later, he was still seeking two.[95]

Mechanical substitutes for hand labour began to appear in England's paper mills at the close of the century. The duster, a rotating wire cylinder connected to the mill's power train, shook rags free of lint and debris, and thereby displaced female workers. Inserted in the vat and turned by a small wheel outside it, the agitator, or 'hog', kept the pulp in 'perpetual motion'and dispensed with manual churning, a task performed by the layman and an apprentice, Desmarest calculated, twenty to forty times a day. [96] But the division of labour around the vats remained unchanged. Combinations among these skilled men had matured slowly; however incomplete, C. R. Dobson's survey of 'Reported Labour Disputes' in Britain made no mention of paperworkers before the 1780s.[97] Evidently, masters and men turned to a craft custom, the 'bull ring,' to thrash out their differences.[98] This practice endured, but amid the bad harvests and swiftly rising prices that accompanied the French Revolution, bargains dissolved rapidly and paternalism grew more costly. The aging Whatman despaired: 'My object having always been to manufacture well, and to give a fair equivalent to my men in proportion to their ability and care, I made them a present at Xmas. One man, who at that period thanked me much for two guineas, the next year demanded four as a right'.[99] In 1788, a cabal of paperworkers had taken shape around Manchester, prompting a printed retort from their employers. Two years later, an indictment for conspiracy named some journeymen from Hertfordshire, who had leagued to secure higher wages.

[92] Quoted in ibid., p. 171.

[93] Ibid., pp. 222-223.

[94] Quoted in ibid., p. 165.

[95] Quoted in ibid., p. 225.

[96] James Cutbush, *Early American papermaking*, p. 64.

[97] C. R. Dobson, *Masters and Journeymen: a prehistory of industrial relations, 1717-1800* (London: Croom Helm, 1980), pp. 24-25, Table 1.2.

[98] On the 'bull ring,' see the summary notes by Jean Stirk in John Balston, *The Whatmans and wove (Vélin) paper: its invention and development in the West* (West Farleigh, Kent: J. N. Balston, 1998), p. 307.

[99] Quoted in T. Balston, *James Whatman* (cit. n. 49), p. 118.

Often paperworkers campaigned for 'Kentish wages and Kentish customs,' since the rewards for sweat in Whatman's home county were generally the best.[100] In 1796, Parliament outlawed the journeymen's trade organisations, but with skill and paper at premiums, this measure had less value than the sheets on which it was printed. A year later, the 'Kent men struck as a body,' and more ominously from their masters' perspective, evidently garnered material support 'countrywide'.[101] In 1800, the workers forged a national combination, the Original Society of Papermakers.

Among the bosses, solidarity and profits proved hard to reconcile, and some broke ranks to use up their pulp, meet excise charges or satisfy customers. The manufacturers were certainly skilled at poaching deft men from their competitors. One producer even incited a walkout in a rival's mill:

> At a time when the plaintiff was in London, the defendant wrote to his journeymen, that the wages of the trade had lately advanced eighteen pence a week, and that if they stood out, they might have the same. The consequence was, that out of thirteen, eleven refused to work, and left his business without a moment's notice.[102]

In 1801, twenty-three manufacturers from Kent and Surrey joined to battle their workers' 'wanton unnecessary and *extortionate demands*' a national coalition followed in 1803.[103] But in the same year, after a dust-up with the masters' combination, the Hampshire firm of Portal and Bridges resolved to avoid 'all [of the manufacturers'] meetings whatsoever thinking it the surest Mode of being on the best of terms with the trade'.[104]

Across the Channel, the Directory also issued a decree in 1796 that banned the paperworkers' cabals, which had a much longer pedigree than their English counterparts. Tired of the journeymen's combined might, Nicolas-Louis Robert, a clerk in a paper mill near Paris, patented a papermaking machine in 1799. In his patent application, Robert testified that '[i]t has been my dream to simplify the operation of making paper by forming it with infinite less expense, and, *above all* [my italics], in making sheets of an extraordinary length without the help of any worker, using only mechanical means'.[105] Simply put, Robert had embedded the journeymen's manipulations in a machine. His device consisted of a continuous belt of woven wire that picked up the pulp, shook it free of water, and wound the infant sheet around a roller. He had demystified the

[100] Quoted in Clement Bundock, *The story of the National Union of Printing, Bookbinding and Paper Workers* (Oxford: Oxford University Press, 1959), p. 357.
[101] J. Stirk, in John Balston, *Whatmans and wove*, p. 307.
[102] Quoted in C.R. Dobson, *Masters and journeymen*, p. 124.
[103] Quoted in D.C. Coleman, *British paper industry*, p. 273.
[104] Quoted in ibid., p. 278.
[105] Quoted in Dard Hunter, *Papermaking*, p. 344.

vatman's shake and the coucher's snap, and laced them together with his mastery of mechanical principles.[106] Papermaking had entered its iron age.

According to Richard Hills, at the time of Robert's invention, 'in England, no attempts had been made to develop any machines for forming the sheet'.[107] But a squabble over rights to the new device quickly divided Robert and his employer, Léger Didot. Didot made sure that diagrams of the machine, samples of its product and finally the original working model found their way to England, where his brother-in-law patented the device in 1801. A pair of London stationers, the Fourdrinier brothers, financed the retooling of the prototype. They set up a workshop in Bermondsey, where the engineer Bryan Donkin transformed the commercial potential of the device into fact. In 1802, Donkin later claimed, Robert's instrument remained 'in a very defective State, it was not at all adapted for the making of Paper'.[108] By 1806, however, a machine installed in a Fourdrinier mill in Hertfordshire offered promise of both mechanical and market success.

Donkin's handiwork soon became known as the Fourdrinier machine. Even the paper furnished by this instrument bore traces of the trade's transnational past, just as speckles and splatters reflected a journeyman's inexperience or sneeze. Around 1756, an anonymous mémoire alerted the Royal Society of Arts to the disadvantages of Hollander beaters: 'The Knotts in the Raggs are drawn through the Engine, and not broke; consequently remain in the Paper, and, if taken out, make a Hole'.[109] Yet, the Fourdrinier machine depended on this Dutch device, warts and all; in fact, the links between the instruments reflected layers of cross-Channel experience, invention and exchange. National borders, then, are too confining for the assessment of papermaking's cosmopolitan mutations; equally, the territorial state and its boundaries imply too much. The papermaking machine was the transnational answer to transnational pressures.

The introduction to this section observes that historians of the Enlightenment emphasise a broadly diffused culture of improvemtn and optimism, while historians of industry centre on the profound difficulty of shifting the skills and materials of partical knowledge. The evolution of hand papermaking and its mechanisation call both themes into question. For harried manufacturers contending with a ravenous excise office and pinched, expensive supplies of rags, the machine promised escape from mounting wages and dependence on

[106] On the connection of the philosophy and principles of mechanical science to industrialisation, see Margaret Jacob and Larry Stewart, *Practical Matter: Newton's science in the service of industry and empire, 1687-1851* (Cambridge, Mass.: Harvard University Press, 2004).
[107] Richard Hills, *Papermaking in Britain* (cit. n. 3), p. 92.
[108] Testimony of Bryan Donkin, 'Fourdrinier Committee,' *British Parliamentary Papers*, 1807, vol. 14, p. 7.
[109] Quoted in D.C. Coleman, 'Premiums for paper', p. 362.

skilled men, as well as many more reams. Mechanisation constituted the path of least resistance for producers eager to be released from any of their trade's familiar tangles. Meanwhile, the practical matters of papermaking and newfound products of natural inquiry, such as the discovery of the bleaching properties of chlorine, restlessy crossed the Channel. The mechanical insight of Robert, the availability of engineers (like Donkin) for hire in England and the English edge in precision, artisanal metalworking together underpinned the creation and refinement of the papermaking machine.[110] Consequently, the English trade was finally unique – until 1817, when the enterprising Gilpin brothers engaged in a touch of industrial espionage and erected a papermaking machine in Delaware.[111]

The Fourdrinier machine suffered a few blows during the Captain Swing riots of 1830, but French, American *and* English mechanics, manufacturers, and engineers reworked it even more aggressively.[112] Each introduced their own technological variations to the basic design. Still, English papermaking was bedevilled by an old worry, the cost of old linen. In 1817, John Dickinson, a prominent manufacturer, feared that 'the Trade has been progressively declining since the Peace, owing in fact to the facility which it has opened of distant markets being supplied from France and Holland, where the manufactured Article is produced for little more than the material Costs in this Country'.[113] With the proponents of free trade triumphant in Britain, the customs duty on foreign paper came off in 1861. At the same time, the Continent and America retained their protective tariffs and, worse yet, export duties on rags.[114] The English industry struggled: as one producer despaired, 'To ask us to sustain a competition with foreign manufacturers under conditions such as these is to place before us a task more hopeless of accomplishment and more cruel in its exactions than that of which the Israelites complained during their bondage'.[115]

110 On English engineers for hire, see Christine MacLeod, 'The European origins of British technological Predominance,' Leandro Prados de la Escosura, ed., *Exceptionalism and industrialisation: Britain and Its European rivals, 1688-1815* (Cambridge: Cambridge University Press, 2004), pp. 111-126, on p. 124. On metalworking, see Peter Mathias, *Transformation*, pp. 32-35.

111 In 1809, John Dickinson, the prominent English paper manufacturer, invented and patented the cylinder version of the papermaking machine. Eight years later, the Gilpin brothers installed a device patterned after Dickinson's instrument.

112 On the breaking of papermaking machines, see Leonard Rosenband, 'Comparing Combination Acts: French and English papermaking in the age of revolution,' *Social history* 29 (2004): 165-185, on pp. 180-181. On French, English and American improvement of the device, see Judith McGaw, *Most wonderful machine: mechanization and social change in Berkshire paper making, 1801-1885* (Princeton: Princeton University Press, 1987), pp. 93-116.

113 John Dickinson, 'Memorial of John Dickinson,' 20 Feb. 1817, TNA: PRO, CUST 48/67.

114 William J. Ashworth, *Customs and excise*, pp. 381-382.

115 Thomas Wrigley, 'Mr. Milner Gibson and the papermakers' (Manchester, 1864), p. 5.

Evidently, Adam Smith had not won over this manufacturer or many of his fellow papermakers. They had trusted too long in the state's protection, their own societies and their less visible arrangements to be tempted by unfettered markets. Wood pulp, which became available in the later nineteenth century, provided one answer, but the forests of North America and Sweden also provided a challenge. Another set of papermaking hybrids had taken root.

Primary sources

'An Account of the Duties on Foreign Paper imported,' n.d., British Library, Add. MSS. 38,387.

'Average Importation of Foreign Paper for 15 Years from 1770 to 1784,' n.d., British Library, Add. MSS. 38,345.

Fourteenth Report of the Commissioners of Inquiry into the Excise Establishment (London, 1835).

Commissioners for Trade and Plantations, 'Paper Manufact[r],' 23 Dec. 1697, British Library, Sloane MSS. 2902.

Desmarest, Nicolas, 'Papier (Art de fabriquer le),' in *Encyclopédie méthodique: Arts et métiers mécaniques,* vol. 5 (Paris, 1788): 463-592.

Dickinson, John, 'Memorial of John Dickinson,' 20 Feb. 1817, TNA: PRO, CUST 48/67.

A Diderot Pictorial Encyclopedia of Trades and Industry: Manufacturing and the Technical Arts in Plates Selected from 'L'Encyclopédie, ou Dictionnaire Raisonné des Sciences, des Arts et des Métiers' of Denis Diderot, vol. 2, edited with Introduction and Notes by Charles C. Gillispie (New York: Dover Publications, 1959).

Dossie, Robert, *Memoirs of Agriculture and Other Oeconomical Arts*, vol. 1 (London, 1768).

Early American Papermaking: Two Treatises on Manufacturing Techniques Reprinted from James Cutbush's American Artist's Manual (1814) with an Introduction by John Bidwell (New Castle, Del.: Oak Knoll Books, 1990).

Koops, Matthias, 'A development of the views and designs of the French nation…' (London, 1796).

Koops, Matthias, *Historical Account of the Substances which Have Been Used to Describe Events, and to Convey Ideas, from the Earliest Date, to the Invention of Paper* (London, 1800).

Lalande, Joseph-Jérôme Lefrançois de, *The art of papermaking*, trans. Richard Atkinson (Kilmurry, Ireland: Ashling Press, 1976). Lalande originally published his *Art de faire le papier* in 1761.

Library of the Royal Society of Arts. *Minutes*.

'Memorial of George Paine,' 11 Feb. 1818, TNA: PRO, CUST 48/73.

'Memorial of Louis Fauche Borel,' 15 Aug. 1812, TNA: PRO, CUST 48/54.

'Petition of the Paper Makers of Great Britain,' 1765, TNA: PRO, CUST 48/17.

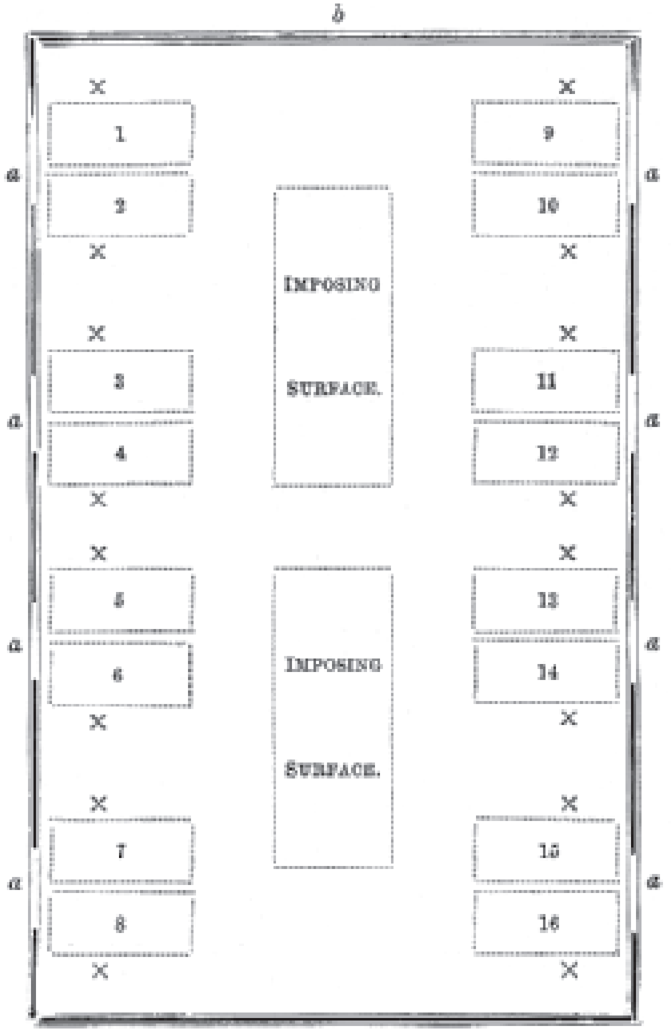
Petty, William, 'A Catalogue of French comodities yearely transported into England,' n.d., Papers of William Petty, British Library, Add. MSS. 72,890.

Testimony of Bryan Donkin, 'Fourdrinier Committee,' *British Parliamentary Papers*, vol. 14, 1807.

Torriano, Nathaniel [?], Speech in the House of Lords, *Manuscripts of the House of Lords*, vol. 10, new series, 1712-1714 (London, 1953).

Whatman, James, 'Some Reasons that make it necessary to alter the present Method of levying the Excise on British made Paper,' 2 Dec. 1764, British Library, Add. MSS. 38,203.

Wrigley, Thomas, 'Mr. Milner Gibson and the Papermakers' (Manchester, 1864).



'General view of a printing office'. This diagram represents a small room at the top of a building, set up as a composing office. It illustrates the careful attention to spatial arrangement that was necessary in a printing house. Everything depends, in fact, on the quality and distribution of light and, after that, on the absence of vibration. The sixteen composing frames are positioned so that each gets 'a fair moiety' of the light from its window (*a*). The compositors are to stand on the spots marked x. 'The first law of the printing-office *must* be 'a place for everything, and everything in its place''. J. Southward, *Practical printing* (4th ed. 2 vols. London: Printer's Register office, 1892), II, 544, 549.

ILLUSTRATION 40

The identity engine: printing and publishing at the beginning of the knowledge economy

Adrian Johns

When people in the eighteenth and nineteenth centuries reflected on the mutual relations between creativity, culture and commerce, they often did so by thinking about printing. From the erudite pages of *philosophes*' works to the loud and proud processions of artisans and masters in European cities, the press was everywhere hailed as 'the art that preserves all arts'. As such, it provided the firm footing on which human progress could ascend. At the same time, the emerging legal doctrine of copyright underpinned a new class of writers able to live by their work, and the circulation routes of the book trade linked an ever-expanding population of readers into a common republic of letters. The Enlightenment, craftsmen and scholars agreed, was a phenomenon of print. The Marquis de Condorcet's *Outlines of an historical view of the progress of the human mind*, translated into English in 1795, made the point most clearly by identifying the press as the pivot on which the history of civilisation turned. The 'revolution that the discovery of printing must bring about' was that between a benighted past and the rational future.[1] Condorcet himself may not have coined the modern concept of a printing revolution, but that hardly matters. His is a representative indication of a vision of print that was shared by many Enlightenment historians and philosophers, including, for example, John Locke, Denis Diderot, Immanuel Kant and – admittedly perhaps not such an Enlightenment figure – Herder.[2] It was out of such sentiments that today's historiographic commitment to that concept grew.

Yet at the same time eighteenth-century print was also a typical early modern craft. That meant that it was permeated by issues of hierarchy, secrecy,

[1] Marquis de Condorcet, *Outlines of an historical view of the progress of the human mind* (London: printed for J. Johnson, 1795).

[2] J. Locke, *Correspondence,* 8 vols. ed. by E. S. De Beer Oxford: Oxford University Press, 1976–89), V, 785; D. Diderot, 'Letter on the book trade,' extracts translated by A. Goldhammer, *Daedalus* 131 2002): 48-56; J. Schmidt ed., *What is Enlightenment? Eighteenth-century answers and twentieth-century questions* (Berkeley, CA: University of California Press, 1996), pp. 58-64; J.G. von Herder, *Reflections on the philosophy of the history of mankind,* ed. F.E. Manuel (Chicago: University of Chicago Press, 1968), pp. 109-11.

credit and cartelism. As much as contemporaries vaunted the powers of the press, they also cautioned against the practical realities of the craft of printing and the commerce of bookselling as they were actually conducted. This kind of warning represented a constant counterpoint to the chorus of praise publicly lavished on the press. Understandings of print and its cultural, commercial and creative impact were therefore much more qualified than we tend now to appreciate. The press might well be the art that preserved all arts *in principle*, but whether it did so in practice, or in any particular case – how faithfully, for which readers and to whose benefit – was not something that could simply be assumed. Authors, readers, governments and institutions all had to engage practically and intensively with the crafts of the press in order to ensure that it lived up to its potential. And Condorcet was at the forefront of this, too, with his efforts to reform the principles of governance and authorship that structured the French book trade.[3] Strange to say, these two sides of Condorcet – and of other writers interested in such themes – have rarely been brought into juxtaposition, then or now. It is time that they were. How could the grand theory of the press be reconciled with the mundane experiences of its protagonists?

To pose that question is to call for a new kind of history of print – one that sees the character of print not as stable and intrinsic to the press, but as changeable over time and across cultures. The ways in which it changed, moreover, were integral to the developing concepts and practices of craft, invention and civility with which this book is concerned. I have already advanced an argument along these lines for the early modern period, ending in about 1720 or so with the first generation of copyright.[4] But in doing so I gestured at the possibility of building on that work to construct a longer history. This longer history would need to deal with the fortunes of print in the industrial revolution, and preferably extend into the post-industrial era too. It would face considerable challenges in doing so. In particular, one of the claims of the original argument was that early modern printing, being a craft, did not manifest the typographical uniformity that commentators since at least Marshall McLuhan had tended to attribute to it, and that such uniformity as it did create was the result of constant labour conducted in particular contexts. With the industrial

[3] This is readily accessible in Marquis de Condorcet, 'Fragments concerning freedom of the press,' extracts trans. A. Goldhammer, *Daedalus* 13 (2002): 57-9; see also C. Hesse, *Publishing and cultural politics in revolutionary Paris, 1789-1810* (Berkeley: University of California Press, 1991), and J. Boncompain, *La révolution des auteurs: naissance de la propriété intellectuelle (1773-1815)* (Paris: Fayard, 2001).
[4] A. Johns, *The nature of the book: print and knowledge in the making* (Chicago: University of Chicago Press, 1998).

revolution, however, print *did* begin to approach high degrees of uniformity, at first in a few privileged instances and then far more broadly. Two innovations in particular represent the crux of the issue. Steam power, it seems, encouraged large impressions with no breaks for correction in mid-run; and stereotyping fixed the page itself in metal. Together these techniques – and especially stereotyping – pose a host of questions for historians used to focusing on culture and contingency, and resistant to determinism too. We need to investigate how the world of craft dealt with these changes: to ask about the fate of skill, the changing places of print and the conceptions of creativity and commerce that accompanied this new kind of enterprise.

This essay offers a start to that endeavour. It makes three principal points. First, it claims that the value attached to craft skill within the book trade was already in decline before these technologies arrived on the scene. Indeed, projectors of stereotyping capitalised on this decline to get a footing for their technique, at a time when the available evidence indicated that it not only offered no economic or aesthetic advantages over conventional typography, but was actually worse in almost every respect. Second, whilst the overt status of craft declined, the necessity for craft itself nonetheless endured. Printers' conventions and skills continued to shape how steam and stereotyping were used and what impacts they had. Third, because of this, printers themselves could plausibly claim that stereotyping *in practice* would not facilitate the fixity of printed works at all. On the contrary: it threatened to make such fixity impossible.

But some printers knowledgeable in the trade went further still. In the end, they claimed, securing texts by machine, even if it could be achieved, was simply not the key to Enlightenment that so many outsiders assumed it to be. In effect, they warned that strangers to the printing house were looking for links between print and progress in the wrong place. They should direct their attention not to machines, but to men, and in particular to the craft skills and moral conventions that they upheld. It was these, they proclaimed, that made print a force for progress. The implications of that claim extended, and continue to extend, very broadly indeed – as far as the very nature of print and its place in history.

Babbage and the booksellers

To understand what this means, one can start with a man who tried to make fixity absolute. In the late 1820s Charles Babbage spent his time scouring the land for manufacturing processes that might be up to the job of building his hugely ambitious mechanical 'difference engine'. He largely failed to find them – indeed, his inquiries helped inaugurate new kinds of accuracy and discipline in such processes – but he did come up with an item of manufacture of his own. It was a book. He entitled it *On the economy of machinery and manufactures*. The volume proved a great success, running to four editions and being reprinted in several countries. It offers a fine introduction to the place of print in the industrial age, for many reasons, not the least of which is that Babbage took the book itself as a chief example of what most characterised that age. But in consequence of that decision, Babbage's book ended up bringing together the two issues that ever since Condorcet we have tended to keep distinct.

Babbage sought to define his age. He declared himself especially impressed by the ability of machines to produce uniformity. 'Nothing is more remarkable, and yet less unexpected,' he wrote, 'than the perfect identity of things manufactured by the same tool'.[5] He gave many examples of this capacity, but repeatedly he returned to the press. 'The same identity pervades all the arts of printing,' he remarked. It did so because in printing, as in other industrial-age machines, the distinctive attribute of the machine was apparently to remove human variability. 'The impressions from the same block, or the same copper-plate, have a similarity which no labour could produce by hand'. No 'inattention or unskilfulness of the operator' could attenuate the uniformity created by a good press. Building on this, Babbage made the manufacture of uniformity into the defining characteristic of the age of manufactures. In a lynchpin chapter entitled 'Of Copying,' he ranged across an extraordinary array of industries to demonstrate that all of them depended on this principle. Metal-casting, waxworks, brick manufacture, the fashioning of pipes for smoking tobacco, the production of wires and tubes – all of these, and many more, he tackled as instances of the mechanically-enabled production of identicalness. And 'the most important in its influence of all the arts of copying,' Babbage avowed, was printing itself.[6] With techniques like lithography and stereotyping taking the very page out of artisanal hands, he declared the dream of absolute fidelity finally within reach. Lithography could be used to produce facsimiles of mathematical tables. Stereotyping, finally, because it guaranteed the identity of copies while still permitting 'trifling' alterations to be made in later impressions, offered the possibility that such tables could 'at last become perfect'.[7]

Babbage concluded this central discussion by taking his own book itself as an instance of manufacturing. He reminded readers of just how many acts of copying had been carried out to create the object they were holding in their

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[5] C. Babbage, *Works*, ed. M. Campbell-Kelly (New York: New York University Press, 1989), VIII, 47.

[6] Ibid., VIII, 52.

[7] Ibid., VIII, 55.

hands. Its pages came from stereotype plates, which were copies of plaster-of-Paris moulds, which came from movable type ('It is here,' Babbage interjected, 'that the union of the intellectual and the mechanical departments takes place'), which themselves derived from matrices, which were copies from punches. Even the punches themselves sometimes incorporated elements copied from further punches. A cascade of faithful copying, made possible by machines, gave rise to this book. The overall result, he concluded, exemplified the same fundamental principle 'as in every other department of manufacture': 'the principle of copying [created] the uniformity and the cheapness of the work produced'.[8]

Babbage's interest in printing processes continued to be manifested throughout the *Economy*. Over and over again, he appealed to such processes as exemplary of the advantages of mechanisation and the division of labour. Thus he instanced at one point the printing of banknotes in Ireland.[9] At another, he used a steam-press to advocate for pneumatic machines.[10] At yet another, he referred to an experiment carried out at a major London printing house to demonstrate the role of machinery in economising on materials.[11] 'The rapid improvements which have taken place in the printing-press during the last twenty years,' he began, 'afford another instance of saving in the materials consumed, which has been well ascertained by measurement, and is interesting from its connection with literature'. Pressmen had traditionally used balls to spread ink, but this had inevitably generated waste ink that had had to be scraped off the balls as a crust; it had also meant that the ink layer itself was never exactly uniform, since it depended on the skills of the men. Babbage claimed to have measured the waste with a modern press using cylindrical rollers at half the level of the old process. Furthermore, this new machine was admirably suited to the introduction of steam power, thus adding a vast economy of time to that of material. Babbage once again drew a general conclusion, this time that 'the most perfect economy was only to be produced by mechanism'.

In what was perhaps the most widely read account of machinery and manufactures of its age, Babbage thus made printing into their very model. But it is worth noticing two points in particular about how he did so. First, he made not printing per se into their model, but stereotyping. This was a deliberate choice, for which alternatives certainly existed. He focused on stereotyping, rather than on the steam press or mechanised papermaking, because it took

[8] Ibid., VIII, 77-8.
[9] Ibid., VIII, 36.
[10] Ibid., VIII, 203.
[11] Ibid., VIII, 44-6.

the page itself out of the realm of skill and art, and made it a mechanical, identical commodity. It stood at or close to two critically important transition points: between artisanal labour and machine labour, and between authorial production and mechanical reproduction. That was what gave it its potential to realise the Enlightenment dream of print uniformity.[12]

But Babbage also had a more specific plan for stereotyping – one that would truly put to the test assumptions about the intrinsic property of the press to fix texts. He yearned for a way to print perfect numerical tables. Such tables had proliferated with the increasing complexity and specialisation of the sciences and practical disciplines. More and more aspects of industrial society depended on them: not only astronomy and navigation, but finance, trade, insurance and even printing itself. Contemporary printers' manuals competed to offer the best 'tables of calculation' for estimating the costs of setting pages in type, and there is every indication that crucial decisions on whether or not to undertake proposed books rested on these devices. Babbage's own Victorian biographer remarked that without accurate tables 'modern science would be an impossibility'. Yet nobody had found a way to ensure their reliability. The authoritative French Board of Longitude tables, for instance, were known to contain at least 500 mistakes. Opinions on this differed; George Airy, to Babbage's cost, felt that the situation was by no means disastrous. But Babbage maintained that It 'was not easy to over estimate the importance of *rendering it impossible for an error to exist in any printed copy of tables*'.[13] And efforts to minimise errors had everywhere (not least in Airy's Greenwich) made table-production into an elaborate social project, involving the combined labours of dispersed and disciplined people using rigorously policed methods.[14]

The labour of table-making was partly that of calculation, but it was also that of page-composition. And in fact many blamed compositors more than calculators for the problem. Augustus de Morgan pronounced that 'a second edition derives no authority from the goodness of the first, because the printer, who is… as important a person as the author in the matter of tables, has again stepped between the latter and the public'.[15] Babbage too reportedly acknowledged that 'the greatest source of error' in tables lay with 'the copyist, the

[12] See comments in D.J. McKitterick, *Print, manuscript, and the search for order* (Cambridge: Cambridge University Press, 2003), p. 215.

[13] H.W. Buxton, *Memoir of the life and labours of the late Charles Babbage, Esq., FRS*, ed. A. Hyman (Cambridge, MA: MIT Press, 1988), p. 48.

[14] See M. Campbell-Kelly, ed., *The history of mathematical tables: from Sumer to spreadsheets* (Oxford: Oxford University Press, 2003).

[15] A. de Morgan, in *Penny Cyclopaedia* (London: C. Knight, 1842), p. 500; quoted in D. Swade, "Unerring certainty'," pp. 148-9.

compositor and printer'.[16] For that reason printers too found the failure to provide fixity in tables a professional embarrassment. In an age of fact, they could not secure the most elementary facts of all. The latest attempt, in revolutionary France, had invoked Adam Smith's principle of the division of labour in an attempt to subdivide the task, and had even dallied with a stereotyping technique, yet it had proved abortive. Dionysius Lardner, who published the best-known exposé of the problem, suggested that the project had run up against human incapacity itself. Human limits inevitably resulted in errors and, tellingly, Lardner claimed that many of these were inherited by successive editions, with the result that mistakes tended to multiply faster than they could be eliminated. It really seemed that there was no way to secure these data. What was needed, Lardner remarked, was a plan 'to throw the powers of thought into wheel-work,' and 'to substitute an automaton for a compositor'.[17]

We have got used recently to acknowledging the displacement of human labour that the mechanisms of industrial science implied, and to recognising the fraught meanings of the term 'automaton'.[18] Lardner's remark reminds us that the workers of print were at risk as well as the workers of science. This was what Babbage thought stereotyping could do – eliminate human craft from the reproduction of data – and it was this that for him gave the technique of stereotyping its great potential for *perfecting* print.[19] Others agreed, de Morgan going so far as to propose forcing table-makers to use stereotype, and it is an assumption that pervades modern accounts of the process too.

Babbage therefore designed his Difference and Analytical Engines expressly to meet this purpose, by connecting the printing of tables directly and inseparably to their calculation. The Difference Engine was in essence two machines of roughly equal complexity (about 4,000 parts each), one to compute the numbers and the other to print them, which it would do by creating stereotype sheets. John Herschel's report on it to the Royal Society in 1829 stressed that both were essential, for if the results were 'transferred to type by the usual process' then 'the whole advantage would be lost'. Pursuing this design, Babbage did extensive personal research on printing presses, plant, type cases and the like, including a visit to see *The Times* in production. As he told Sir Humphry Davy, he was determined to find 'a substitute for the compositor

16 H.W. Buxton, *Memoir*, pp. 70-71, 146ff, 219-20.

17 D. Lardner, 'Babbage's calculating engine,' *Edinburgh Review* July 1834; repr in C. Babbage, *Works*, II, pp. 118-86, esp. 119, 122-39.

18 E.g., S.J. Schaffer, 'Babbage's dancer and the impresarios of mechanism,' F. Spufford and J. Uglow, eds., *Cultural Babbage: technology, time, and invention* (London: Faber and Faber, 1996), pp. 53-80, esp. 77.

19 For this aspect see also D. Swade, 'The 'unerring certainty of mechanical agency': machines and table making in the nineteenth century,' M. Campbell-Kelly, *Mathematical tables*, pp. 145-74.

and the computer' alike. And for the printing part of his machine he took inspiration from various branches of the trade, including the use of pewter plates to print music and a composing machine invented by an American named Church. His own device would have ten boxes of type, one for each digit. In conversation with Herschel he learned about a printing house in Glasgow that had tried to eliminate 'the errors which are found in different copies of the same edition of a work' by passing a thin wire through holes drilled in the type to keep each line intact. The technique had been discarded by the Glaswegian house as too expensive, but Babbage adapted it by using grooves on the edge of each piece both to prevent the wrong character from being used and to hold lines of type together – two sources of error known to have occurred in other tables.[20]

Babbage had confessed to Davy that the whole idea would look 'Utopian', and in the event it defeated him. Work came to a halt shortly after his book appeared.[21] Perhaps ironically, the only difference engine to be built at this time was a simpler device constructed by a printer. George Scheutz of Stockholm was captivated enough by Lardner's advocacy to condemn both himself and his son to bankruptcy in a quest to build it.[22] Yet if printers contributed to Babbage's art, so he, in a sense, contributed to theirs. In light of the sections of *On the economy of machinery and manufactures* to which they gave rise, Babbage's printing researches took on a strange significance. If his device as a whole was a Difference Engine – so called because it calculated values by iteratively adding small differences – then the stereotyping printer on which it was to have depended could have been called an Identity Engine. It manufactured identicalness. As such, it promised to realise in one small but critically important sphere the ideal described so consistently in Babbage's book.

Yet the second point about Babbage's *On the economy of machinery and manufactures* is that it was also exemplary in a very different way of the world it described. When the book appeared, it was a stereotyped commodity, to be sure. But it almost did not appear at all. And this was a result of the everyday people, practices and places of the book trade – of print in practice. In

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[20] H.W. Buxton, *Memoir*, pp. 65-7.

[21] C. Babbage, *Works*, II, pp. 13; 29-32; H.W. Buxton, *Memoir*, pp. 70, 86; A. Hyman, *Charles Babbage: pioneer of the computer* (Princeton: Princeton University Press, 1982), p. 112. The Engine was not in fact built until recently, at the Science Museum in London. Interestingly, one of the few substantial modifications introduced in the Science Museum version was to introduce a clutch between the Engine and the Printer so that they could be decoupled. In the original design they were to operate together on a single drive shaft. See D. Swade, 'The construction of Charles Babbage's Difference Engine No. 2,' *IEEE Annals of the history of computing* 27 (2005): 70-88, esp. 83-4.

[22] M. Lindgren, *Glory and failure: the difference engines of Johann Müller, Charles Babbage and Georg and Edvard Scheutz*, trans. C.G. McKay (Cambridge, MA: MIT Press, 1990).

particular, Babbage's problem lay with publishers' reactions to a decision taken by the author himself. Towards the conclusion of the volume – as he was proofing its pages, in fact – Babbage had rather suddenly decided to include a chapter on what he called 'combinations of masters against the public'. Almost the whole chapter was devoted to a particular combination that, Babbage said, 'operates upon the very pages which are now communicating information respecting it'. He referred to a cartel of publishing booksellers that operated in the capital. This cartel, he charged, corrupted the whole culture of publishing in Britain.[23]

Once again Babbage made his own book an exemplar of his argument. He described its manufacturing and publishing costs in considerable detail, along with the terms for remunerating the author, publisher and retailer. We do not have to rehearse the details here. His point was that retail booksellers were making up to 44% profit on each copy sold. This rate of profit, he thought, was unjustifiable. It had remained suspiciously constant for years, despite changes in the rates of profit arising from capital in other manufactures. He maintained that it only persisted because of a 'conspiracy' maintained by the major booksellers. A small cadre schemed to prevent anyone from selling books at less than approved prices. They forced their counterparts to sign a document to this effect, and refused to sell books at customary discounts to anyone who declined. This, Babbage said, 'left the small capitalist no option between signing or having his business destroyed'. Ultimately almost the whole trade – some 2,400 people – had felt compelled to sign. Several had then tried to evade the rules, only to be betrayed by 'spies' and 'placed under the ban of the combination'. Meanwhile, far from publicly acknowledging the cartel, its ruling 'committee' refused to give copies of the regulations even to those booksellers who had signed them.

Babbage's view of all this was the view of the classical free trader. He denounced as 'the weakest of all arguments' any claims that large profits were needed to counteract losses from books that failed to sell, since this merely meant levying a private tax on the purchaser to offset a business's own 'want of skill'. Similarly, objections that he had 'exposed too freely the *secrets of trade*' cut little ice: 'The only *real secrets of trade* are industry, integrity, and knowledge'. To him, so-called underselling was merely an artefact of the publishers' conspiracy. 'This excessive rate of profit has drawn into the book trade a larger share of capital than was really advantageous,' he explained, and

[23] Incidentally, the *publisher* was a relatively new social kind in the 1820s. It had emerged out of the desire of a few booksellers to deal exclusively in copies rather than selling books at retail. To be a publisher in this period thus meant adopting and adapting moral and practical conventions from an identity that was increasingly recognized as distinct. This should be borne in mind in what follows.

underselling reflected 'competition between the different portions of that capital'. Without the conspiracy to restrain them, many an 'industrious bookseller' would dearly like to sell Babbage's own book for the far more reasonable return of 11%. But the combine acted 'to prevent the small capitalist from employing his capital at that rate of profit which he thinks most advantageous to himself'.

His curiosity and sense of injustice piqued, Babbage went on to recite a litany of other practices that structured the world of print, serving the trade's interests at the expense of those of author and public alike. For example, printers routinely charged higher rates to non-members of the trade, thus militating against newcomers and authors. And then there was the so-called 'overplus'. A ream of paper comprised about 500 sheets, which was why printers charged in units that large. But in reality a ream was 516 sheets, the extra 16 generally being used for revises. But in mechanised printing plants – or in those houses where the skills of artisans were sufficiently refined – this allowance was excessive. There were therefore typically several extra copies made of any book. For his own, of which 3000 copies were printed, Babbage knew that 52 extra were finished. Printers occasionally tried to take advantage of this uncertainty to make even more copies, and to sell them surreptitiously. For that reason expedients had sometimes been adopted, such as the use of a special watermark in Laplace's *Mécanique Céleste*. 'In London there is not much danger of such frauds,' Babbage conceded, but that was only because of the importance of a good reputation. Here, 'printers are men of capital, to whom the profit on such a transaction would be trifling, and the risk of the detection of a fact, which must of necessity be known to many of their workmen, would be so great as to render the attempt at it folly'. In other countries these practices were routine.

Babbage found all these kinds of practices reprehensible. As with the other attributes of printing, their import transcended the industry itself. It was high time, he announced, that in general 'such conventional combinations between different trades should be done away with'. The reason extended to the very character of the nation. 'In a country so eminently depending for its wealth on its manufacturing industry,' Babbage cautioned, 'it is of importance that there should exist no *abrupt* distinction of classes'. The aristocracy must be connected to the economic wellsprings, and the capitalists, masters and artisans must equally see their way to rise in the hierarchy. Differential pricing, combinations, preferences and the like were all barriers to this. Their abolition would improve the basic civility that defined British society.[24]

[24] C. Babbage, *Works*, VIII, p. 221.

Babbage proceeded to specify what he thought should be done. He held a jaundiced view of any notion that the public could be recruited to fight in its own interest. Not least, the offending booksellers were also the proprietors of most of the authoritative periodicals and newspapers of his age, such that the latter 'ought to be regarded merely as *advertising machines*'. The public should be on guard against reviews of any issues implicating a journal's proprietor – and such implication often could not be discerned without privileged knowledge, precisely because the booksellers maintained so many unannounced alliances. In fact, Babbage warned, 'until reviews are established in which booksellers have no interest, they can never be safely trusted'. This meant that the public sphere would be no ally; it would not even be public in any true sense. He was more sanguine about authors, however, and entertained cautious optimism that they could be persuaded to 'destroy' the booksellers' combine. Babbage sketched out the rudiments of what he called a 'campaign against Paternoster Row'. It centred on the idea of authors forming a 'counter-association' ranged against the publishers. This counter-association would hire an 'agent' with good connections in the trade, to handle sales, negotiations and distribution for the authors directly. Not only would it circumvent the publishers' cartel; it would also enable authors to price their own books, thus facilitating a political-economic revolution in the world of ideas, since 'the public would have the advantage of reduction in price produced by competition between authors on the same subject'. Finally, it would generate a new review venue to replace what Babbage decried as the compromised vehicles of the 'quarterly advocate of despotic principles' (presumably the *Quarterly Review*) and the 'sceptre of the northern critics' (the *Edinburgh Quarterly*). 'The advancing intelligence of the age' demanded 'new organs, equally the representatives of its intellectual power, and of its moral energies'. His counter-association would provide them.[25]

As it appeared, then, Babbage's book not only gave mechanised printing a defining role in its characterisation of the age, and not only used itself as exemplary of that role, but also culminated in a polemic against the monopolising conspiracies that mechanised printing still left possible. Despite his frank optimism about the prospects for scientific progress represented by stereotyping, he reckoned that such practices corrupted the public sphere. The charge struck a chord. His polemic against contemporary publishing practice as 'morally and politically wrong,' and his call for 'complete reform,' attracted far wider notice than he had anticipated. Some of that notice came from the publishers themselves. Babbage had expressed himself confident that prudence

[25] Ibid., VIII, p. 229.

would prevent their seeking to obstruct his message. That expectation was soon proved too sanguine.

The booksellers were not about to take such charges lying down. Their reaction showed the fragility of too rosy a view of the realities of the mechanised book trade. First, Babbage's publisher wrote to him at the last moment to withdraw from the project, citing the passage on the book trade as his reason; he even refused to return duplicate proofs of that section, keeping them to show anyone who asked why he had withdrawn.[26] Babbage had to scramble for an alternative. He settled on the utilitarian Charles Knight, who issued the Society for the Diffusion of Useful Knowledge's *Penny Magazine*, pioneered stereotyping and steam printing for a mass audience, and himself denounced the 'bigoted' combinations of his fellow publishers in favour of a new 'modern epoch of cheap literature'.[27] The choice made the polemical identity of *On the economy of machinery and manufactures* within the publishing world still clearer. Babbage now found that several London booksellers boycotted the work. Yet it was nevertheless a success, and in a preface to the second edition he remarked that the print-run of 3,000 copies had sold out in three months. But in that second edition the publishers fought back in the book itself, pointedly intervening in Babbage's authorised text. They inserted an extra printed page containing a 'Reply to Mr Babbage' that rejected outright his charges of suppression. They cited the numbers of copies they had bought 'on speculation' to claim that the combine had in fact supported his work.[28] Babbage knew nothing of this interpolation, hearing about it from a copy mailed to him anonymously. Only in the third edition could he reply. He did so by availing himself of Knight's financial accounts, pointing out that prior to publication the combine had not subscribed for anything like the numbers they suggested. They had bought copies in bulk only once the demand had been proven, and had therefore done nothing to support the book. Besides, he concluded, 'The main question, and the only important one to the public,' was that of the combine itself. The axioms of free trade 'and the importance of diffusing information at a cheap rate' must lead public opinion to repudiate the cartel once and for all.[29]

Babbage's call was never answered, but then that is partly the point. This testy exchange with all the leading publishers of what was the world's leading publishing centre helps explain why Babbage's accounts of print are worth our

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[26] B. Fellowes to C. Babbage, 25 March 1832 and 4 June 1832: British Library Ms. Add. 37186, fols. 427, 453.
[27] C. Knight, *The old printer and the modern press* (London: J. Murray, 1854), pp. 238-9, 243.
[28] C. Babbage, *Works*, VIII, p. xii.
[29] Ibid., VIII, pp. xiv-xv.

time. In the first place, Babbage articulated more clearly and with greater technical thoroughness than anyone before the twentieth century the desire for print to furnish an absolute standard of identity in the objects it produced, along with the view that this kind of identity was a prerequisite for progress, especially in the sciences. A simpler version of this conviction was central to many popular accounts of print, then as now, but none of those came anywhere near Babbage's perspicacity, none aspired as he did to mesh the general argument with the specifics of printing as machinery and manufacture, and none embedded an understanding of the practice in anything like his all-embracing political economy of manufactures. Also, none identified the transition to this absolute standard so completely with stereotyping, such that its adoption represented a clear break from hand to machine. But in the second place, his problems with 'combinations' in the trade revealed how even such grandiose claims depended in practice on customs in the printing and bookselling communities that he, like many others before and since, would rather wish away as local, ephemeral and accidental. In truth, the contrast between his utopian aspirations and his struggle against the publishers reflected something that was not ephemeral at all. Such trade conventions were elements of the book trade at least as old as the press itself, and probably older. They were still widely honoured. And the reality of print rested on them. Babbage's specific examples – the overplus, differential charging, pricing cartels and so forth – were 1830s versions of the very practices that had shaped the trade for many generations. Their defenders held that the publishing of worthy books depended on them. Whether it would be possible to disentangle the manufacture from the conventions was very much at issue, not only in Babbage's time but also long before. And long after, too: think of the debates over the Net Book Agreement in our own generation.

Babbage got the evidence for his charges from three principal sources. One was a recently printed statement by a bookseller named William Pickering condemning what Pickering called the 'Booksellers' Monopoly'.[30] The second was a letter that Babbage received, apparently out of the blue, after he had decided to take on the publishers but before he had composed his chapter. It came from another bookseller, this time a publisher of law books named Frederick Wollaston.[31] Saying that his brother (Alexander Luard Wollaston, FRS) had told him of Babbage's intent, Wollaston regaled him with information on 'the iniquities of Booksellers'. Where Babbage's information about the workings of the combine did not originate with Pickering, it generally came

[30] W. Pickering, *Booksellers' monopoly. Address to the trade and to the public* (London: C. Whittingham, 1832). The only copy I know of is at Yale University.

[31] F.L. Wollaston to C. Babbage, 17 April 1832: British Library Ms. Add. 37186, fol. 349.

from Wollaston. But the third source is perhaps the most interesting. It was a parcel of evidence that had been presented to a Parliamentary committee back in 1818. This was Babbage's main source for all wider matters concerning the trade's practices, like the differential pricing to non-tradesmen and the conventions surrounding overplus copies. In appealing to this evidence, Babbage was helping himself to the results of an earlier campaign. But that campaign had not been directed against combinations. It had been concerned instead with copyright.

If there could be a way of reconciling technology, mundane trade practices and the vast cultural potential of print, then by the 1800s copyright was the leading contender to achieve that goal. Indeed, Babbage himself concluded his polemic with a word of advice to a would-be author that made copyright pivotal. He counselled the newcomer to brave the combines and strike out on his own – a course that had been recommended to the learned for generations, incidentally, generally to no good effect – but in any case to preserve above all his property. Whatever happened, '*he should by no means sell the copyright*'. That Babbage's exposé of publishing should culminate in this distinctly impassioned plea (he was not one to overuse italics) reminds us that copyright had become *the* organising principle of commerce and creativity in print. But it had not been so for long, and it was by no means uncontroversial even by his time. Babbage's appropriation of evidence from a campaign against copyright provides us with an access point through which to perceive the deeper history and wider resonance of the case he was trying to make.

Copyright and the eclipse of craft

Critiques and defences of craft had seen the book trade fissure in the century prior to Babbage's work. What had begun as an artisanal enterprise centred on mastery of the craft had become a speculative capitalist practice centred on property rights in 'copies'. However much Babbage might decry the lingering idiosyncrasies of artisans, the eclipse of craft in the book trade had already gone a long way by the time stereotyping appeared. It had been supplanted by the regime of copyright. Recalling that the printing house itself was a place with a history, an identity and a cultural role can help us to understand what exactly it was that changed in this process, how it changed and why those changes rankled.

The collective, customary authority within an early modern printing house was called its 'chapel'. The chapel created hierarchies, sustained complex celebratory events and upheld a ritual calendar. Within a chapel, all the inhabitants of the printing house, from the 'devils' up the master himself – and, in principle, authors too – knew their places.[32] Further, chapels enforced 'bylaws', the lists of which could become quite long. Some such norms, it is worth noting, coalesced with communal conventions extending far beyond the house itself. So, for example, members were forbidden to abscond with surplus printed sheets, lest a rival use them to launch a competing impression. These sheets were equivalent to the overplus that Babbage later encountered, and it is significant that the conventions surrounding them were originally chapel ones. Similarly, a printing-house custom emerged of 'posting' titles to new works, and this gave rise to a kind of street-level copyright convention, especially useful in places like Dublin where copyright itself had no legal status until 1800. Even the uniformity that printing created came about from the application of skill through machinery in a chapel setting. Joseph Moxon, the seventeenth-century printer who published the first guide to the craft, averred as much, insisting that journeymen must possess 'a competency of the Inventer's Genius' if the books they printed were to manifest such uniformity. It was an important and paradoxical point, often neglected in modern histories: to reproduce an original with exactitude required real interpretative art.

Since the mid-seventeenth century, however, master-printers had been losing their place of honour in the hierarchy of the book trade. A new kind of bookseller arose, later called the publisher. For this figure craft skill was not a qualification. The booksellers established their own, new moral economy, based not in skill but in literary property. To be specific, it rested in 'copy rights,' as they were termed. A major distinction was thus introduced into the manufacture and distribution of printed pages. Copy-owning booksellers secured investment, oversaw distribution and took decisions as to a book's appearance, market and impact. Printers, on the other hand, feared being reduced to 'mechanic' operators, expected merely to obey rules and instructions. The bookseller rather than the master craftsman became the go-between linking the worlds of printing and politeness. The booksellers achieved this in part by acting together against rivals, through the formation of semi-formal alliances. The combine that Babbage encountered was a descendent of those eighteenth-century groups.

As publishing booksellers rather than printers came to dominate the book trade, and decision-making was resituated into the bookseller's parlour, so the moral status of the chapel was cast into doubt. At the same time, master printers tried to adapt by increasing the scale and homogeneity of their workplaces. The practice of hiring apprentices to do the work of journeymen – long

[32] For a marvellous example of chapel culture, see W. Blades, *An account of the German morality-play, entitled 'Depositio cornuti typographicae': as performed in the 17th and 18th centuries* (London: Trübner, 1885).

practised on the quiet – now became brazen, and many journeymen saw the chapel becoming a manufactory. But as this occurred, so the conventions of the chapel seem to have been elevated in the perceptions of artisans themselves. Resistance to their erosion grew and sometimes turned into outright conflict. Chapel members responded with denunciations, pamphleteering, and occasionally violence, directed primarily against the master printers who they saw as directly responsible, or else against those workers who collaborated, as it were. The best-known example, whether or not it refers to a real incident, is the 'great cat massacre' described by Nicolas Contat as occurring in Paris.[33] But there were many other little insurrections – earlier in England, later in France and Ireland, and later still in America. In Dublin, to cite just one, a secret society began to attack printers who colluded in the employment of apprentices. In one case the target – significantly, the oldest artisan in the city, and therefore in traditional terms the bearer of seniority – was severely beaten, and his wife lost her hand.[34]

Moreover, a *historical* distinction was also increasingly evident to printers. Journeymen perceived themselves to be separated not only socially (from an elite that controlled their work while ignorant of the craft), but temporally (from a past in which the skilled practice of that craft had been a basis for steady advancement). They could not see how to advance in the trade now, but at the same time they became ever more convinced that in previous times it *had* been customary to rise. Both aspects of this belief were constructs built on the evidence available to eighteenth-century printing chapels – evidence of memory, custom, texts and rituals. Yet both were strongly held. A complex brew of history, experience, observation and talk thus fomented conflict over the chapels.

In London, that conflict reached a climax with an attempted coup against the body that represented the trade as a whole, the Company of Stationers. It was led by Jacob Ilive, a radical printer with a background in Grub Street and an idiosyncratic and highly complex deist cosmology.[35] Printing, Ilive told his fellow workers, was the greatest social bond ever invented, not because of its machinery but because of the communal bonds between chapel members.[36] He published the entire set of rules by which the book trade operated

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[33] R. Darnton, *The Great Cat Massacre, and other episodes in French cultural history* (London: Allen Lane, 1984).

[34] National Library of Ireland, Guild of St. Luke papers, Ms. 12125, pp. 46-9.

[35] Ilive will appear in greater detail in my future book, *Piracy*, but for now there is a preliminary treatment available online in A. Johns, 'Grub Street pirates and the plausibility of print,' at http://csb.princeton.edu/index.php?app=download&id=9.

[36] *The Speech of Mr. Jacob Ilive to his brethren the Master-Printers* (London: n.p., 1741).

– something denounced as a revelation of trade secrets – in order to urge that typical radical's dream, a return to a primitive constitution.[37] Then he called on discontented printers to overthrow the hierarchy. Unfortunately for them, the Company refused to accept his 'rebellious election,' and the revolution fizzled out. But it then responded with a formal step that made manifest exactly the process that Ilive and the chapels most feared. Once and for all, the Company formally disenfranchised all journeymen. Speculative capital explicitly replaced craft skill at the defining heart of the trade.

The legal principle that upheld the ascent of the publishers over the printers, or, as many in the chapels saw it, of political economy over moral economy, was copyright.[38] Yet the reign of copyright was never entirely secure, and the early nineteenth century saw its own challenge to this order of print. It too abhorred the eclipse of craft skill. It was motivated not by opposition to literary property *per se*, however, but to the particular form that it had taken. Copyright had become entangled with a requirement to deposit works in institutional libraries. That requirement had begun in rather ad hoc fashion almost two centuries earlier, but by now it had come to be associated strongly with the Enlightenment aspiration for a universal library.[39] For some, however, it represented an onerous tax on knowledge itself. Works that were expensive to produce and appeared in very small impressions particularly fell afoul of it. Natural history often fell into this category, as did antiquarianism and bibliography – all of them important and fashionable topics at the close of the eighteenth century. But to relieve the depository requirement necessitated that the whole issue of copyright itself be revisited.

The ensuing campaign was led by someone perhaps as far removed from Ilive as could be imagined: a maverick Romantic poet, novelist and critic named Sir Samuel Egerton Brydges. From 1810 Brydges lived at an old manorial home in Kent called Lee Priory, where he ran a press devoted to the production of fine editions in small impressions. This press took on the role of an exemplary alternative to a culture of print dominated by copyright. Where copyright generated vacuous popularity, shallow imitation and ephemeral fame – Alexander Pope being in Brydges' view an early case in point – a virtuous

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[37] See *The charter and grants of the Company of Stationers* (n.p. [London: J. Ilive], 1762), reprinting the relevant portions of *The charter and grants of the Company of Stationers of the City of London* (London: printed by R. Nutt, 1741).

[38] The standard work on this is M. Rose, *Authors and owners: the invention of copyright* (Cambridge, MA: Harvard University Press, 1993). By *moral economy* I mean, of course, the kind of ethically 'permeated' notion identified by E.P. Thompson in 'The moral economy of the English crowd in the eighteenth century,' E.P. Thompson, *Customs in common* (New York: New Press, 1993), pp. 185-258, e.g., 188.

[39] For this aspiration see R. Chartier, *l'Ordre des Livres: lecteurs, auteurs, bibliothèques en Europe entre XIV^{e} et XVIII^{e} siècle* (Paris: Alinea, 1992), pp. 69-94.

alternative should vaunt true original Genius. The Lee Priory press thus sought to restore to view an entire genealogy of poets whose memory had been obliterated, it implied, by commercialised print. It never addressed a *public*, which Brydges associated with the cheapened creative realm brought about by copyright. The smallness of its print-runs was itself a statement of Romantic despair at the possibility of genius's appealing to a readership corrupted by commerce. The enterprise was thus never going to be a commercial success. But it eventually produced more than fifty works, and what these fifty represented was an alternative history of literary creativity itself. If Condorcet hailed printing as revolutionary, then the reactionary Brydges furnished a pointed riposte. He wanted a printing counter-revolution.[40]

Meanwhile Brydges campaigned to expose the iniquities of a book trade and library culture centred on copyright. It was this campaign that led to the committee report on which Babbage drew for his own denunciation of publishers' combines. The publishers Longman, then the employers of William Pickering, were prominent supporters. They took pains to itemise the practices of such print in order to establish their claims. So, for example, Babbage's point about printers charging by the ream came from the evidence that these earlier campaigners had collated, which showed that issuing another 11 copies on top of 500 (as the deposit required) was disproportionately costly, since it broke into the next ream. The result was that works of learning – they cited Humboldtian natural history – could not be produced at all. Their case against the libraries rested partly on an assertion that such trade conventions were robust and in practice unchangeable. And this was what really struck readers of the committee's report. Brydges and his allies meant to point up the injustice of the libraries' demands; but what they achieved in fact was to reveal the customs of the book trade itself to a sceptical phalanx of laissez-faire observers. The committee's investigations went nowhere, then; but its evidence survived, to be used by Babbage to mount his own case against the very craft conventions that it had been designed to bolster.[41]

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[40] There is a large but scattered literature on Brydges, but his campaign about copyright and deposit has not received much attention. The primary sources are plentiful, however. See especially S.E. Brydges, *A summary statement of the great grievance imposed on authors and publishers* (London: Longman, Hurst, Rees, Orme and Brown, 1818); S.E. Brydges, *Answer to the further statement ordered by the Syndics of the University of Cambridge* (London: Barnard and Farley, 1818); [R. Duppa], *An address to the Parliament of Great Britain, on the claims of authors to their own copy-right* (2nd edition. London: sold by Longman, Hurst, Rees, Orme and Brown, 1813); S.E.Brydges, *The autobiography, times, opinions, and contemporaries of Sir Egerton Brydges*, 2 vols. (London: Cochrane and M'Crone, 1834); and, in general, R.C. Barrington Partridge, *The history of the legal deposit of books throughout the British Empire* (London: The Library Association, 1938).

[41] J. Feather, *Publishing, piracy, and politics: an historical study of copyright in Britain* (London: Mansell, 1994), pp. 113-8.

Ill. 41. 'An unwelcome intruder'. George Cruickshank's cartoon captures compositors' anxieties at the prospect of a typesetting machine being welcomed into their office. J. Southward, *Progress in printing and the graphic arts during the Victorian era* (London: Simpkin, Marshall, Hamilton, Kent & Co., 1897), 50. Courtesy of the University of Chicago Library.

Stereotyping skills

If copyright succeeded craft as the lynchpin of the order of print, therefore, it did not do so without profound objections from several sides. The chapels resisted the eclipse of craft as the calibrator of status within the trade, the free-traders attacked combinations and Romantics and reactionaries denounced what they saw as the commercialisation of creativity wrought by the system of literary property and library deposit. All sides concurred that what was happening was not an emancipation from skill, but a subjection to a different kind of skill: that in speculation.

It was at this point that technological change began proceeding at a dazzling pace. Starting with papermaking, as Rosenband shows in his essay, almost every enterprise in printing and publishing passed through a generation of rapid mechanisation. The one instance where mechanisation did *not* make headway, that of composing, was not for want of inventions; but this was the one part of the printing house in which craftsmen remained secure (Ill. 41), and they resisted mechanisation successfully until later in the century. Meanwhile steam and stereotyping intruded into the preserve of the already weakened pressmen. They confirmed and bolstered the transformation in the workplace of print that was already under way. Indeed, their adoption depended on this being so.

Stereotyping was again the case in point. Very similar processes had been tried many times before, but had always failed to make headway. The version that finally succeeded derived from Charles Mahon, third earl of Stanhope – a radical, pro-Jacobin ally of Priestley, and a habitual projector of inventions, among them steamships, techniques for preventing forgery, a logotype system and, above all, a very successful iron printing press. He was also the inventor of an arithmetical machine (which ended up in the hands of Babbage's son), a universal logic based on reducing all propositions to statements of identity and a machine called the Demonstrator that Stanhope built to display that logic in action.[42] This Demonstrator was a crude device, in no way a progenitor of Babbage's engines; nonetheless, the conjunction of a logic based in an arithmetic of identity-statements, an aspiration to mechanise that logic and the invention of stereotyping techniques to produce identity in print, is temptingly suggestive. One can perceive similar conjunctions between mechanism, replication and reason in other inventive entrepreneurs of this period, such as James Watt and Thomas Jefferson, both of whom invented copying machines. There is insufficient evidence to pursue this point very far in Stanhope's case, but it does indicate that the desire to produce machines for accurate and reliable replication was a common and fruitful one in this generation.[43]

Contemporaries signalled their awareness of the changes partly by vocabulary. They did not call the steam press a *press* at all, but a *machine*.[44] When one of them began operation at *The Times*, the change took place literally overnight, for fear of unrest among printers about to see their chapel obliterated. That was in November 1814; by 1827, *The Times* was churning out 5,000 copies an hour. Print runs ten or a hundred times as great as had ever previously been viable represented a quantitative leap of the same order as that associated with Gutenberg. To its boosters, such as Knight, steam facilitated the first bestsellers, the first national daily press, and a new round of attempts to 'improve' the labouring populations by disseminating 'useful knowledge'. It was not just that the new machinery facilitated production and distribution, moreover, but

[42] R. Harley, 'The Stanhope Demonstrator,' *Mind* 4 (1879): 192-210; G. M. Ditchfield, 'Stanhope, Charles, third Earl Stanhope (1753–1816),' *Oxford Dictionary of National Biography* (Oxford: Oxford University Press, 2004). Papers relating to Stanhope's inventions are at the Center for Kentish Studies, Maidstone, Kent, Ms U1590/C711.

[43] S.A. Bedini, *Thomas Jefferson and his copying machines* (Charlottesville: University Press of Virginia, 1984). I owe the general point to Lissa Roberts.

[44] A.C. Dooley, *Author and printer in Victorian England* (Charlottesville: University Press of Virginia, 1992), p. 78.

that it changed radically *what* was produced and distributed. A journal like *Chambers's Magazine* could only exist because it could be stereotyped, steam-printed and distributed across the country by rail, and its format and content were deliberately designed for this.[45] Knight's steam journal *The printing machine* took pride in making the machine itself an emblem of progress, and giving it a prominent place in the very literature of 'useful knowledge' that it itself created.[46]

The printers promulgated their own views of the technique that so captivated Babbage, in the so-called 'grammars' of printing that flourished in this period. These volumes claimed to describe the art's history, tools and practice.[47] Two of the most influential appeared in 1824 and 1825. Both bore the same title, *Typographia*. But their authors were radically different. One was the work of John Johnson, Brydges' erstwhile printer at Lee Priory, who had left Kent in a welter of lawsuits to set up operations in London. The other was written by Thomas Hansard, radical son of a famous Tory printer to Parliament. Johnson saw the new machines in terms of an almost Ilivian regard for craft; Hansard maintained that they should be considered in terms of science and political economy. Yet it is poignant that even Hansard, who employed stereotyping himself, proved reluctant to endorse the more revolutionary claims made for the technique. He ended up agreeing with his antiquarian counterpart: craft, for all that had happened in his generation, remained a crucial part of the enterprise of print. In particular, fixity itself continued to depend on it.

Johnson originally mooted his *Typographia* in 1818, as the parliamentary committee was working. He wrote it, he confessed, in conditions of 'mental affliction' after the collapse of the Lee press.[48] Eventually appearing in 1824, it occupied two volumes, the first of which was devoted to a celebration of the history of the art in terms of the great Renaissance scholar-printers who had defined its nature. None of the individuals discussed, needless to say, was a bookseller, and the history ended when booksellers began their rise, at the end of the sixteenth century. The second volume then comprised the 'grammar' proper, being a practical guide to the printing house itself. It was with this second half that the point of Johnson's book became clear. It was in large part an elegy. Far from hailing the advances of the new age, Johnson

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45 J. Sutherland, *Victorian fiction: writers, publishers, readers* (London: MacMillan, 1995), pp. 87-106.

46 *The printing machine: a review for the many* 1 (15 February, 1834).

47 A comprehensive selection of excerpts from these books is available in R.G. Rummonds, ed., *Nineteenth-century printing practices and the iron handpress*, 2 vols. (New Castle, DE: Oak Knoll Press/ British Library, 2004).

48 J. Johnson, *Typographia*, 2 vols. (London: Longman et al., 1824), I, p. viii.

believed that in the first two decades of the nineteenth century London printing had 'made a retrograde, instead of a progressive movement'. This, he thought, had come about in three stages. The first had been the conflicts with the journeymen, which (he agreed with Ilive) had culminated in a 'ruinous' system of employing rootless apprentices rather than maintaining real artisans. The second was the advent (or revival, as Johnson carefully called it) of stereotyping. And the third was the 'baneful' introduction of steam machines. These machines, Johnson declared, had completed a catastrophic decline in a once-proud art, because they had been put to use in a struggle for cheapness rather than quality.[49] The principles of political economy led steam to ruin print.

Like Babbage, Johnson focused especially on stereotyping. He loathed it. And he thought he had powerful arguments against its adoption. It raised composing and proofing costs, for example. Any savings were merely soaked up by booksellers – an indication of collusion. Pressmen themselves 'detested' the technique, and demonstrated as much by refusing to mention flaws in plates. In a real printing house, therefore, 'numerous errors are likely to arise, even by that process which was stated to be perfection itself'. The very permanence of the plates was a flaw, too, since 'no alteration in the size of the page, or cut of the type can ever take place'. They could never be made substantially *better*. And finally, given the practices of the trade, stereotyping encouraged fraud. The bookseller would be unable to detect 'any unjust advantage which might be taken of him, in point of number, by those with whom he entrusts his work'. It was the problem of supernumerary copies again – what Babbage identified with the overplus. This possibility, Johnson concluded, was decisive against stereotyping. He thought it 'sufficient to deter all persons from giving it the least countenance or support in any way whatever'.[50]

Johnson's volumes put on display a 'reciprocity of interests' between employer and employed that he thought was needed for 'any branch of Art or Manufacture,' but that stereotyping imperilled. Elaborate woodcuts and engraved frontispieces (Ill. 42) and perfectly composed 'Tables of Calculation' displayed the worth of the human skills under threat. That worth therefore extended pointedly to pagefuls of numerical data. Thus reminded of the stakes, the British public, he hoped, would never knowingly embrace machines 'which

[49] Ibid., II, p. 645.
[50] Ibid., II, pp. 657-9. The term *stereotype* itself was invented by Firmin Didot in Paris in 1795, as part of the revolutionary regime's project to print tables, but similar processes were developed many times in the seventeenth, eighteenth, and early nineteenth centuries. See G.A. Kubler, *A new history of stereotyping* (New York: Little & Ives, 1941), pp. 23-71, and Kubler, *Historical treatises, abstracts, and papers on stereotyping* (New York: Brooklyn Eagle, 1936).

Ill. 42. 'Typographia'. John Johnson's sacral, regal and heraldic vision of the pedigree of the printer's craft. Within 'a rich ancient screen placed before a chapel or shrine' is shown a representation of Henry VIII promulgating the English Bible. Beneath are the armorial emblems of the celebrated early masters Gutenberg, Fust (Faust), Elzevier and Aldus, along with those of three early centres of printing, Mainz, Strasbourg and Harlem. The two statues are of Gutenberg and Aldus Manutius. The hall at the foot of the image portrays the Bodleian Library in Oxford, 'a Library particularly rich in early Typography,' and it too is surrounded by the arms of its patrons. J. Johnson, *Typographia* (2 vols. London: Longman et al., 1824), II, frontispiece. Courtesy of the University of Chicago Library.

can only tend to damp and destroy all the energy and talent of those who have hitherto upheld and exercised the Art'. Specifically, Johnson wanted a tax levied to equalise the economics of steam and manual printing. Such a tax would be justifiable, he thought, because, given the realities of the London book trade, the public gained nothing from the machines. The publishers simply pocketed the profits. The booksellers' combine thus lay at the heart of this printer's case against stereotyping.[51]

Hansard, on the other hand, was exhilarated by the rate of change since 1800. He was happy to embrace both steam printing and stereotyping in his own business. He might therefore have been expected to mount a decisive defence of the new machines. But in fact he was far from unqualified in their praise. He recalled some of the more hyperbolic pronouncements that their advocates had made – in particular, the claim that stereotyping provided absolute fixity – only to deny them with all the acuity of a well-informed practitioner. Again and again, he appealed to the mundane realities of the printing house to cut the ground from under the high theories of stereotype boosters. For example, Andrew Wilson, an early collaborator with Stanhope, had maintained that stereotyping offered '*security* against *error*'. He had claimed that it removed all the mistakes that compositors made – mistakes that meant that successive printed editions typically became less and less correct. 'The certainty of the stereotype plates remaining correct,' Wilson claimed, 'may be almost as fully relied on as if the possibility of error did not at all exist!'[52] Of all this Hansard was sceptical. He denounced above all the claim that conventional printing necessarily proliferated errors. This was a 'calumny' on 'the respectable part of the press'. Responsible printers were quite capable of improving the accuracy as well as the appearance of successive editions, he insisted. The creation and perpetuation of reliability in print was a matter of *how* and *by whom* a piece of printing was done.[53]

Hansard gave an example of how stereotyping itself could foster errors, in the form of Robert Nelson's *Fasts and festivals*, a Church calendar that he himself had reprinted periodically from type since 1805. The example was utterly counterintuitive. If stereotyped, Hansard observed, each successive edition would in fact be 'much worse in appearance' than if set from type. After all, printers renewed their type periodically, whereas stereotype plates

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[51] J. Johnson, *Typographia*, I, p. xi.

[52] T.C. Hansard, *Typographia* (London: Baldwin, Cradock & Joy, 1825), 827. For Wilson, see G.A. Kubler, *The era of Charles Mahon, third earl of Stanhope, stereotyper, 1750-1825* (New York: G.A. Kubler, 1938), pp. 22-66.

[53] T.C. Hansard, *Typographia*, p. 833-4n.

inevitably wore down. But it was not merely a matter of aesthetics. 'I may further add,' Hansard continued, 'and can *prove*, that, without any thing more than proper attention in the reading department, the correctness of the editions has been improving also'. This progress, inherent in a responsible printing house, could not have occurred with stereotyping. In fact, the text itself would have degraded. Repeated use of the plates would inevitably have damaged them, and repairs were invariably partial and error-prone. If stereotyped, then, 'the work would have been gradually sinking, instead of rising in appearance to meet the improved state of modern printing'. This, Hansard insisted, was the reality of a printing house. What produced accuracy was not the single application of a machine but the steady, progressive application of a skill.[54]

Hansard was quite prepared to accept that stereotyping had its place. That place, tellingly enough, was in the production of mathematical tables. He even invoked a trade belief that the technique had been invented for this purpose, in revolutionary France, as part of the same tabulating project that Babbage and Lardner cited for its failure. And Hansard concluded his account of the new technique by proudly revealing that he himself was achieving accuracy progressively by a moderate admixture of skill and machinery in this sphere. He had been using stereotype plates to print tables for nautical volumes. It was the only application for which he found the technique undeniably useful.[55]

In 1825, therefore, this well-informed printer's reflection on the relation between skill and mechanism in his industry arrived at the same point from which Charles Babbage was about to start. This was the point on which Hansard and Babbage – printing and science – converged. But when considering grand cultural claims about print's powers, Hansard *retreated to* the tables whereas Babbage wanted to *advance from* them. Hansard thought tables were the last refuge of the stereotyper, Babbage that they were his base-camp. Babbage asserted that fidelity lay in the elimination of craft by mechanism. Hansard maintained that mechanism would always fix, not a text itself, but the text as mediated through skills. To seek for perfection in this was a category mistake. Rather, one should look for progress in the repeated application of those skills themselves. Even he, among the friendliest of all printers to the new technologies, insisted on this. The distinction between these two views of stereotyping had everything to do with the history of craft in the printing house, and with its resilience in a mechanistic age.

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54 Ibid., p. 843.

55 Ibid., p. 845.

Primary sources

Babbage, Charles, Correspondence. British Library, London, Ms. Add. 37186.

Babbage, Charles, *Works*, 11 vols. ed. M. Campbell-Kelly (New York: New York University Press, 1989).

Blades, W., *An account of the German morality-play, entitled 'Depositio cornuti typographicae': as performed in the 17th and 18th centuries* (London: Trübner, 1885).

Brydges, S.E., *A summary statement of the great grievance imposed on authors and publishers* (London: Longman, Hurst, Rees, Orme and Brown, 1818).

Brydges, S.E., *Answer to the further statement ordered by the Syndics of the University of Cambridge* (London: Barnard and Farley, 1818).

Brydges, S.E., *The autobiography, times, opinions, and contemporaries of Sir Egerton Brydges*, 2 vols. (London: Cochrane and M'Crone, 1834).

The Charter and grants of the Company of Stationers (n.p. [London: J. Ilive], 1762).

Condorcet, Marie-Jean-Antoine Caritat, Marquis de, 'Fragments concerning freedom of the press,' extracts trans. A. Goldhammer, *Daedalus* 131 (2002): 57-9.

Condorcet, Marie-Jean-Antoine Caritat, Marquis de, *Outlines of an historical view of the progress of the human mind* (London: printed for J. Johnson, 1795).

Diderot, Denis, 'Letter on the book trade,' extracts translated by A. Goldhammer, *Daedalus* 131 (2002): 48-56.

[Duppa, R.], *An address to the Parliament of Great Britain, on the claims of authors to their own copy-right* (2nd edition. London: sold by Longman, Hurst, Rees, Orme and Brown, 1813).

Hansard, T.C., *Typographia* (London: Baldwin, Cradock & Joy, 1825).

Harley, R., 'The Stanhope Demonstrator,' *Mind* 4 (1879): 192-210.

Herder, J.G. von, *Reflections on the philosophy of the history of mankind*, ed. F.E. Manuel (Chicago: University of Chicago Press, 1968).

Ilive, J., *The speech of Mr. Jacob Ilive to his brethren the Master-Printers* (London: n.p., 1741).

Johnson, J., *Typographia* (2 vols. London: Longman et al., 1824).

Knight, C., *The old printer and the modern press* (London: J. Murray, 1854).

Lardner, D., 'Babbage's calculating engine,' *Edinburgh Review* July 1834; reprinted in C. Babbage, *Works*, II, pp. 118-86.

Locke, John, *Correspondence,* 8 vols. ed. by E. S. De Beer (Oxford: Oxford University Press, 1976–89).

National Library of Ireland, Guild of St. Luke papers, Ms. 12125.

Pickering, W., *Booksellers' monopoly. Address to the trade and to the public* (London: C. Whittingham, 1832.

The printing machine: a review for the many 1 (15 February, 1834).

Southward, J., *Practical printing* (4th ed. 2 vols. London: Printer's Register Office, 1892).

Southward, J., *Progress in printing and the graphic arts during the Victorian era* (London: Simpkin, Marshall, Hamilton, Kent & Co., 1897).

Epilogues

Towards a genealogy of modern science

Peter Dear

Anglophone historians of early-modern science have largely given up on using the word 'science' as a designation of all the things that we want to study. A common working solution is to talk about the history of 'the sciences,' a terminology which, although necessarily imperfect, is a lot less anachronistic than 'science'. Alternatively, some historians appear to believe that they can say 'natural philosophy' for the early-modern period and yet continue to think 'science,' a move that fails on a number of counts. One of the sets of dichotomous categories clearly present in the foregoing chapters, for example, is that between 'natural philosophy' and 'mathematics,' a distinction that was part of the basic architecture of formal knowledge in the sixteenth and seventeenth centuries, and still in play in the eighteenth. Thus, Dijksterhuis's essay raises very important issues regarding the finer structure of this dichotomy, one that in effect addresses the question of how such a thing as a *mathematical* natural philosophy became possible by the later seventeenth century. Dijksterhuis recognises two distinct classes of mathematical work in the period, one of them being 'contemplative,' formalistic mathematics (of the sort practised by Descartes), the other being the trade of the so-called mathematical practitioners of which Jim Bennett has taught us so much, and that Ash discusses in his essay.[1] Dijksterhuis shows how the analytical distinction between those two classes (in the case of dioptrics, thoroughly imbricated) carried a heavy social valence with it too. It seems, in fact, that mixed-mathematical fields such as optics invaded the domain of natural philosophy on two different but interrelated fronts: one the contemplative or intellectualist front, and the other

[1] A striking story from John Aubrey illustrates further Dijksterhuis's point: Descartes 'was so eminently learned that all learned men made visits to him, and many of them would desire him to shew them his Instruments (in those dayes mathematicall learning lay much in the knowledge of Instruments, and, as Sir Henry Savile sayd, in doeing of tricks) he would drawe out a little Drawer under his Table, and shew them a paire of Compasses with one of the Legges broken; and then, for his Ruler, he used a sheet of paper folded double'. Oliver Lawson Dick, ed., *Aubrey's Brief Lives* (Harmondsworth, Middlesex: Penguin Books, 1972), p.185.

the practical, manipulative, instrumental front.[2] But Henninger-Voss's essay reminds us that those two fronts were also combined within the newly-constituted high culture of humanist scholarship itself.

A number of further conceptual dichotomies underlie the chapters in this book, whether explicitly or implicitly: among them are theory/practice, science/technology, craft knowledge/scientific knowledge and tacit knowledge/formal knowledge. The authors have addressed a wide variety of problems that arise from such juxtapositions, and that reveal an inherent instability. For the historical analyst, the tangle of inter-related dichotomies often seems to render impossible a clear articulation of the central themes to be investigated. Talk of 'science' versus 'technology' has long served to obscure, as much as to illuminate, the question; accordingly, by focusing on the historical vagaries of the term 'science,' I hope to bring a degree of clarity to the issue. 'Science,' in its familiar universalised sense, is really a nineteenth-century rather than early-modern label.[3] Nonetheless, an emerging enterprise in the seventeenth century, with direct forebears in the sixteenth, begins to show some of the more prominent characteristics of what later comes to be called 'science'. It can be recognised in the relationship between the two modes by which mathematics infiltrated natural philosophy: the contemplative and the instrumental.

Histories of the sciences from the seventeenth and eighteenth centuries – works by Gassendi, for instance, or Adam Smith's *History of Astronomy* – constructed similar historical narratives, and lumped together similar groups of enterprises, as those found in histories of science in the nineteenth century – even though the complex of activities recognised in the earlier period cannot, on good historicist grounds, have been the same thing as the category 'science' with which it was later identified by the Victorians. So what *was* this eminently co-optable enterprise of the earlier period that proved such a congenial and recognisable model for the new 'scientists' of the nineteenth century? What was the nature of the earlier cluster of fields preceding that of 'science' properly so-called – an older enterprise the integrity of which is evidenced by eighteenth-century classifications of practitioners and legitimating storylines that were well-established long before the nineteenth century?[4]

[2] Cf. Peter Dear, *Discipline and experience: the mathematical way in the Scientific Revolution* (Chicago: University of Chicago Press, 1995), chap. 6, on physico-mathematics.

[3] See, for a broad-brush picture of this view, Andrew Cunningham and Perry Williams, 'De-centring the 'big picture': *the origins of modern science* and the modern origins of science,' *British journal for the history of science* 26 (1993): 407-432.

[4] A useful recent collection of studies on early-modern histories of the sciences is the special March, 2006, number of the *Journal of the history of ideas*, edited by Anthony Grafton. See also Rachel Laudan, 'Histories of the sciences and their uses: a review to 1913,' *History of science* 31 (1993): 1-34.

The kind of unified storyline that was subsequently co-opted for use in nineteenth-century histories of science seems to have been created in the seventeenth century. This storyline involved particular kinds of characters and particular kinds of moral and intellectual virtues. By the end of the seventeenth century, the various component enterprises (natural-philosophical, mathematical, and medical, to name the chief among them) had begun to coalesce, in such groups as the Royal Society of London and the Royal Academy of Sciences in Paris, into the vision of a unified enterprise associated with a *new* kind of (what was often still called) 'natural philosophy'. The essays in this book have brought out strongly the role of a functioning theory/practice dichotomy in the ideology informing this emerging coalescence. The negotiable world of 'theory' and 'practice,' seen as flexible actors' categories rather than as natural kinds, invites study of how such categories are historically constructed and maintained. The historically-contingent theory/practice distinction appears in much of Jim Bennett's work on early-modern mathematics: in the sixteenth century the mathematical sciences were routinely distinguished into 'theorical' and practical parts (*theorica* and *practica*). Such distinctions often mapped onto social demarcations too: at the end of the eighteenth century, as Schaffer's essay illustrates, the controlling theoretical mind of the experimental naval architects started to dominate the skilled practice of the dockyard shipwright – shipbuilding falling into the mixed-mathematics category celebrated by D'Alembert in the *Encyclopédie*. But the mathematical sense of 'theory' differed in important ways from another theory/practice distinction of the eighteenth century in which the relevant 'theory,' unlike the *theorica* part of a mathematical science, concerned natural philosophy. By the eighteenth century, a large-scale reconstitution of such categories was already taking place, including the formulation of new categories such as 'Newtonian'.

For most historians of science, the label 'Newtonian' is notoriously imprecise; its uncritical application to any particular historical actor in the eighteenth century can obscure as much as it reveals.[5] Robert Schofield's well-known article of 1978 painstakingly established that point for the intellectual history of science by presenting an elaborate taxonomy of eighteenth-century Newtonianisms.[6] Nonetheless, contemporary invocations of Newton's name were ubiquitous, and that fact alone enjoins us not to ignore the label. A Newtonian

[5] The most prominent dissenter from this view is Margaret C. Jacob, who takes 'Newtonianism' to be a specifically-definable intellectual enterprise with direct instrumental consequences for technological development. See, for example, her *Scientific culture and the making of the industrial West* (New York: Oxford University Press, 1997).

[6] Robert E. Schofield, 'An evolutionary taxonomy of eighteenth-century Newtonianisms,' *Studies in eighteenth-century culture* 7 (1978): 175-192.

ideology of knowledge surely existed in the eighteenth century, if only in rather inchoate form, and was oriented around the connotations of the term 'Newtonian'. It was an ideology that associated intelligibility with practical operation, but at the same time it refused simply to operationalise natural philosophy so that the latter becomes nothing more than systematised practice: 'Newtonianism' insisted on a crucial philosophical component that revealed (perhaps God-given) truths about the physical world itself.

The problems and ambiguities inherent in this ideology are nicely expressed by the self-styled Newtonian Buffon. This is what Buffon wrote in his famous preface to the first volume of *Histoire naturelle* (1749), in his polemical attack on systematics:

> In this century itself, where the Sciences seem to be carefully cultivated, I believe that it is easy to perceive that Philosophy is neglected, and perhaps more so than in any other century. The arts that people are pleased to call scientific have taken its place; the methods of calculus and geometry, those of botany and natural history, in a word formulas and dictionaries preoccupy almost everyone. People imagine that they know more because of having increased the number of symbolic expressions and learned phrases, and pay no attention to the fact that all these arts are nothing but scaffolding for achieving science, and not science itself....[7]

What Buffon called 'scientific arts,' then, were bodies of technique that were good for calculating and classifying. But since such arts necessarily lacked insight into causes and the natures of things, they failed to produce true science, or philosophy.

Similar themes appear, albeit less explicitly, in the work of Benjamin Franklin. Franklin can, of course, be represented as some species of 'Newtonian,' as I. Bernard Cohen did more than fifty years ago.[8] Cohen rested his characterisation especially on Franklin's use of Newton's speculations on matter-theory in the *Opticks*. Yet Franklin's electrical studies also involved what one might call a Buffonian strain of Newtonian ideology too. As Jessica Riskin has noted, Franklin's electrical work of the 1740s borrowed from familiar elements of commercial culture and contemporary political economy – centrally, in his conceptualisations of his experimental work in the terms of conservation of electric charge, balancing credits and debits.[9] Franklin the Philadelphia printer

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[7] Georges-Louis Leclerc, comte de Buffon, *Histoire naturelle, générale et particulière*, Vol. 1 (Paris, 1749), 'Premier discours,' p. 52 (my trans.).

[8] I. Bernard Cohen, *Franklin and Newton* (Philadelphia: American Philosophical Society, 1956).

[9] Jessica Riskin, 'Poor Richard's leyden jar: electricity and economy in Franklinist France,' *Historical studies in the physical and biological sciences* 28 (1998): 301-336; see also Christian Licoppe, *La formation de la pratique scientifique: Le discours de l'expérience en France et en Angleterre, 1630-1820* (Paris: Éditions La Découverte, 1996), pp. 169-74.

scrupulously balanced the books in order to make sense of electrical behaviour: a characteristically 'Newtonian' ambiguity between making sense of electricity by claiming to understand its true nature, and learning how to manage electricity – in the latter case, doing the kind of enumeration that his French admirer Buffon regarded as rather superficial philosophically (it was his ideas about the nature of 'electrical fire' that Buffon professed to admire). Franklin played both games simultaneously, and inextricably, and in many respects he looks like a prototype of the nineteenth-century scientific expert, doling out practical advice about lightning rods while talking about the underlying nature of matter.

The creation of the twin categories 'science' and 'technology', and others functionally similar to them, has involved the expenditure of much energy in establishing the appearance that there is indeed a fundamental difference between the two. This active creation of difference between domains claimed to be categorically distinct from one another is why the now-popular term 'technoscience' has such limited usefulness in historical work, whatever its validity in the metaphysical absolute.[10] A particularly stark example from 1751 appears in one of the central documents of the Enlightenment, the 'Preliminary Discourse' to the great *Encyclopédie*. D'Alembert (or, conceivably, Diderot)[11] talks about the knowledge possessed by artisans, and how it can or cannot be codified into the sorts of articles on trade procedures that the *Encyclopédie* will be presenting. The learned man, he says, is going to find it very difficult to master the knowledge involved in artisanal work; he will be unable simply to ask an artisan what's going on and get a useful answer. This is because

> it is through the long-established habit of conversing with one another that the workers understand one another, and this is accomplished much more by the repetition of contingent actions [*conjonctures*] than by the use of terms. In a workshop it is the moment that speaks, and not the artisan.[12]

Such arguments imply a certain character to the notion of the 'public sphere' in which knowledge is being made. A criterion of intelligibility that focuses on language, on what can be said and codified, implies a particular sort of person to acquire or possess that knowledge. D'Alembert seems to withhold from

[10] The term's currency stems from Bruno Latour, *Science in action: how to follow scientists and engineers through society* (Cambridge, MA: Harvard University Press, 1987), pp. 174-75. See, however, Ursula Klein's essay in this volume.

[11] It is a perennial debate as to which parts of the preliminary discourse were written by D'Alembert and which, perhaps, by Diderot.

[12] Jean le Rond d'Alembert, 'Discours préliminaire de l'Encyclopédie,' in *Oeuvres complètes de d'Alembert* (Paris: Belin, 1821), vol.1, pp. 17-99, on p.94. I vary slightly from the translation by Richard N. Schwab: Jean Le Rond d'Alembert, *Preliminary Discourse to the Encyclopedia of Diderot* (Indianapolis: Bobbs-Merrill, 1963), p.124, which contains the excellent translation of *conjonctures*.

artisans the possession of actual knowledge, even though they 'know,' as it were, how to do things. Elsewhere he says:

> there are some trades so unusual and some operations so subtle that unless one does the work oneself, unless one operates a machine with one's own hands, and sees the work being created under one's own eyes, it is difficult to speak of it with precision.[13]

For the project of the *Encyclopédie*, the whole purpose is precisely to be able to *say* something: linguistic expressibility is D'Alembert's basic criterion for knowledge.

D'Alembert ends the 'Preliminary Discourse' with an interesting specification of his proper audience. 'It's for the reading public to judge us: we believe we ought to distinguish it from that which [merely] speaks'.[14] These are the people who constitute D'Alembert's ideal 'public sphere'; they certainly seem to be the kind of people that Habermas identified.[15] But following Tom Broman in taking that 'public sphere' as an ideology more than a social reality,[16] we can also see how that ideology was available to be exploited by those purporting to speak for nature: they spoke for nature to the extent that they were accepted as speaking for us, where the 'us' is the mythical 'public'. D'Alembert effectively makes a sharp demarcation between artisans and learned philosophers (and their readership); between head and hand.[17] The contingencies surrounding the exact nature of such distinctions is the place where historical investigation needs to start; Simon Werrett's account, above, of the shifting relationship between showmanship and industry plays on just these sorts of ambiguous social framings.

Early-modern engagements with formal knowledge of nature, and especially the employment of new uses of the term 'natural philosophy' in the seventeenth century, betray a movement towards an uneasy accommodation between, on the one hand, natural philosophy in its classical sense of a contemplative branch of philosophy, and on the other an endeavour aimed at practical utility and instrumental application. That accommodation was facilitated by the development from the seventeenth century onwards of an explicit,

[13] D'Alembert, 'Discours préliminaire,' p.94, following Schwab, p.123.
[14] Ibid., p.99, varying from Schwab, p.140.
[15] Jürgen Habermas, *The Structural Transformation of the Public Sphere: An inquiry into a category of Bourgeois society*, trans. Thomas Berger (Cambridge, MA: MIT Press, 1989 [1962]).
[16] Thomas H. Broman, 'The Habermasian public sphere and "Science 'in' the Enlightenment,"' *History of Science* 36 (1998): 123-149. On the public sphere as an ideology, see also Harold Mah, 'Phantasies of the public sphere: rethinking the Habermas of historians,' *Journal of modern history* 72 (2000): 153-182.
[17] Cf. Steven Shapin and Barry Barnes, 'Head and hand: rhetorical resources in British pedagogical writing, 1770-1850,' *Oxford review of education* 2 (1976): 231-54.

theorised kind of experimental practice that could link claims about the nature of the world to instrumental techniques for exploiting it. But the accommodation never truly clicked; it never became truly 'natural' – even though it was routinely represented as if it were.

If people ever since the eighteenth century have understood 'science' to mean, essentially, 'natural philosophy' – for contemplative understanding of the world – then the nineteenth century's category of 'applied science' can be regarded as an unproblematic by-product of 'pure' science, which is natural philosophy. Complementarily, if people since the eighteenth century have understood 'science' to mean, essentially, 'instrumentality' – the capability for utilitarian control of nature – then the status of natural philosophy is as a set of accounts of nature, belief in the truth of which is justified by the very fact of its discursive implication in the instrumental work itself. Those have been two distinct ways of representing what 'science' is, but they have not always, or typically, been clearly distinguished one from the other. Instead, there has usually been an implicit relationship of bootstrapping between them, each supporting the other when only one of them is attended to at a time. But if they are interrogated side-by-side, the circularity, and hence non-necessity, of their mutual support becomes evident. This situation, which modern science has directly inherited from its early-modern justificatory traditions, incorporates the basic ideology of modern science.[18] It is an ideology which is curiously reproduced in modern historiographical practices concerning early-modern science itself.

The development of professional history of science in the period following the Second World War revolved around certain narratives of what was called 'the Scientific Revolution'. That label carved out a temporal period that began in the late-fifteenth/early-sixteenth centuries, and usually ended in the early eighteenth century with the work of Newton (with the qualified exception of Herbert Butterfield's 'postponed scientific revolution in chemistry'[19]). Two main versions of the story dominated. One, the true hegemon, used Alexandre Koyré as its patron saint, and treated the stakes of the Scientific Revolution as essentially intellectual: what was really important was the emergence of new ideas about the natural world; that is, new forms of natural philosophy understood in its contemplative sense. In that version of the Scientific Revolution, figures such as Francis Bacon were too prominent to

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[18] Peter Dear, 'What is the history of science the history *of?* early modern roots of the ideology of modern science,' *Isis* 96 (2005): 390-406; also Dear, *The intelligibility of nature: how science makes sense of the world* (Chicago: University of Chicago Press, 2006), introduction.

[19] Herbert Butterfield, *The origins of modern science 1300-1800* (New York: Free Press, 1965 [1949]), chap. 11.

be ignored, but were usually presented in the form of views concerning the potential practical spin-offs that might one day be expected from intellectual scientific activity. Bacon, in the end, was seen as a bad philosopher the praise for whose writings was, when all was said and done, undeserved.[20]

The second version of the story was most often merely tolerated as a foil to the first; a straw man (its opponents hoped) that could be introduced so as to point up the virtues of the chief alternative. But that other version had its own intellectual integrity and explanatory force, in the hands of such as Edgar Zilsel and Benjamin Farrington. In the crucial case of Bacon, Farrington in particular stressed his significance as a 'prophet' of modern science seen explicitly, not as 'natural philosophy,' but as 'industrial science,' while Zilsel and others emphasised the placement of this characterisation of Bacon within a developing artisanal culture in the sixteenth and early seventeenth centuries; aspects of this view were subsequently adopted, albeit in a much more intellectualised form, by Paolo Rossi.[21]

Rich accounts of the sparring relationship between these two historiographical programmes can be, and have been, given that pay close and appropriate attention to culturally-localised settings within the anglophone academic community, British and American.[22] It is also important, however, to see how the materials for these opposing projects lay ready to hand in a historically deep-seated contrast between head and hand, theory and practice, 'natural philosophy' and 'instrumentality,' with immediate sources in early-modern European knowledge enterprises of the sort canvassed in this book.

[20] Alexandre Koyré, *Études galiléennes* (Paris: Hermann, 1966), p.12, describes the view of Bacon as a founder of modern science as a 'plaisanterie'.

[21] A famous collection of papers by Boris Hessen and other Soviet scholars appears in N. I. Bukharin et al., *Science at the cross roads* (London: F. Cass, 1971 [1931]). Zilsel's famous articles from the 1940s are collected in Edgar Zilsel, *The social origins of modern science* (*Boston studies in the philosophy of science*, vol. 200), ed. Diederick Raven, Wolfgang Krohn and Robert S. Cohen (Dordrecht: Kluwer, 2000); Benjamin Farrington, *Francis Bacon: philosopher of industrial science* (London: Lawrence and Wishart, 1951); see also J. D. Bernal, *Science in history* (London: Watts, 1954); Paolo Rossi, *Philosophy, technology, and the arts in the early modern era*, trans. Salvator Attanasio (New York: Harper and Row, 1970). For a recent examination of related historiographical issues of the 1930s and '40s, see Michael Aaron Dennis, 'Echoes of the past: Henry Guerlac and radar's historiographic problem,' Oskar Blumtritt, ed., *Tracking the history of radar* (Piscataway, NJ: IEEE, 1994).

[22] See esp. Anna-K. Mayer, 'Setting up a discipline: conflicting agenda of the Cambridge history of science committee, 1936-1950,' *Studies in history and philosophy of science* 31A (2000): 665-689; idem, 'Setting up a discipline, II: British history of science and 'the end of ideology',' *Studies in history and philosophy of science* 35A (2004): 41-72; Michael Aaron Dennis, 'Historiography of science: an american perspective,' John Krige and Dominique Pestre, ed., *Science in the twentieth century* (Amsterdam: Harwood Academic Publishers, 1997), pp. 1-26.

Modern philosophical approaches to the sciences have tended to reproduce the same purificatory sorting rituals as those found in historiographical traditions. Anglophone philosophers of science, ever since they began to become professionally recognisable as such in the nineteenth century, have tended to frame their questions about science in terms of its capacity to solve epistemological problems. Beyond the familiar twentieth-century ranks of logical empiricists and scientific realists, philosophers of science such as Arthur Fine, Bas van Fraassen or Ian Hacking are still centrally interested in the status of scientific knowledge claims concerning nature; as if science were fundamentally a matter of natural philosophy.[23] By contrast, Marxist philosophical approaches have characteristically focused on elaborating philosophically perspicuous histories of science, not restricted to those concerned with the Scientific Revolution, and have generally opposed the idealist philosopher's one-sided 'natural philosophy' view of science with an equally one-sided view of it as nothing more than 'instrumentality'. Joseph Needham and his collaborators, in the many volumes of *Science and Civilization in China*,[24] provided, on the one hand, material on cosmological ideas (included, no doubt, because they resemble the natural-philosophical content of European science); on the other hand, and constituting by far the bulk of the work, they also discussed technical work and innovations – navigation, making paper or gunpowder, printing, chemical processes and so on. The nature of science as a knowledge enterprise failed to arise as a problem for Needham, because the guiding assumption is that science is, at root, a kind of technical industrial enterprise. From that perspective, its natural-philosophical dimension reduces almost to the epiphenomenal.[25]

It is of great importance that a major strand of modern science descends from a pre-modern endeavour, natural philosophy, that did not use claims to underpinning instrumentality as grounds for accepting its credibility – any more than did the natural philosophies of non-European societies. The instrumental

[23] See especially the classics by Arthur Fine, *The shaky game: Einstein, realism and the quantum theory* (Chicago: University of Chicago Press, 1986); Bas C. van Fraassen, *The scientific image* (Oxford: Clarendon Press, 1980); Ian Hacking, *Representing and intervening: introductory topics in the philosophy of natural science* (Cambridge: Cambridge University Press, 1983). More recent texts exemplify a similar overall stance, e.g. Ronald N. Giere, *Science without laws* (Chicago: University of Chicago Press, 1999); Nancy Cartwright, *The dappled world: a study of the boundaries of science* (Cambridge: Cambridge University Press, 1999). John H. Zammito, *A nice derangement of epistemes: post-positivism in the study of science from Quine to Latour* (Chicago: University of Chicago Press, 2004), examines the development of views of 'science-as-epistemology' in the emergence of science studies.

[24] Joseph Needham et al., *Science and civilization in China* (Cambridge: Cambridge University Press, 1954-2004).

[25] Cf. the view of science as 'instrumental rationality,' as represented in Jürgen Habermas, *The theory of communicative action*, 2 vols., trans. Thomas McCarthy (Boston: Beacon Press, 1984).

dimension of modern science is, from this perspective, a distinct, culturally contingent element. It is neither simply a necessary justificatory prop for natural philosophy, nor does it necessarily rely on science's natural philosophy for its effectiveness. Modern science as a specific kind of cultural practice in the European tradition is an ideological construct involving a dialectical interaction between natural philosophy and instrumentality.

In keeping with such a genealogical approach to understanding modern science, the present book emphasises the material reality of ideas themselves and the ways in which they live and move and have their being – a kind of 'post-*Laboratory Life*'[26] perspective that pays attention to the ways in which 'ideas' are abstracted accounts of what people do – including especially how they produce and manage texts as practical 'literary inscriptions'. It also, symmetrically, emphasises the intellectual content of material manipulation itself. Early-modern Europe saw the production of a number of ideologies of knowledge, including most importantly the two ideologies into which the historiography mentioned earlier divides itself. Natural knowledge as a matter of 'knowing' (or 'natural philosophy') formed an uneasy counterpart to natural knowledge as a matter of 'doing' ('technics' or technology).[27] Such a representation had the ontological effect of creating two different realms of being: one was purely intellectual, and contained things called 'ideas' and 'theories'; the other was material, and discussed objects and their physical manipulation. Much historiography of science ever since has played on, evaded or alternated between these two basic conceptions. Countering the committed historiographical positions that we have all inherited, in which each side has been concerned to diminish the significance of the other's version of 'the Scientific Revolution,' this book attempts at once to 'materialise' ideas through its concern with texts and their uses, while at the same time infusing practical doing with intellectual meaning: doing ideas. Thus ideas become complex concatenations of actions in the world, while 'doing' becomes imbued with practical intellectual content.

Places, sites of knowledge, necessarily loom large in this book: dockyards, polders, printing houses, goldsmiths' workshops, instrument makers' shops, libraries, paper manufactories, canals. Most such places witnessed the performing of practical work, and most, too, have here proved to be inhabited by scholars. Did the latter do more than just get in the way? The answer is clearly 'yes,' but only to the extent that they are seen as *not just* scholars; just as

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[26] Bruno Latour and Steve Woolgar, *Laboratory life: the [social] construction of scientific facts* (Princeton: Princeton University Press, 1986 [[1]1979]).

[27] See, on the intellectual history of the modern term 'technology,' Eric Schatzberg, '*Technik* comes to America,' *Technology and culture* 47 (2006): 486-512.

artisans and workmen must be seen as more than brute manipulators. The conventional distinction between head and hand has been much more of an ideological construct than a necessary feature of reality – albeit often a contingent feature of social reality that also lives on in much historiography of science.

Primary sources

Buffon, Georges-Louis Leclerc, comte de. 'Premier discours,' *Histoire naturelle, générale et particulière*, vol. 1. (Paris, 1749).

Dick, Oliver Lawson, ed., *Aubrey's Brief Lives* (Harmondsworth, Middlesex: Penguin Books, 1972).

D'Alembert, Jean le Rond, 'Discours préliminaire de l'Encyclopédie,' *Oeuvres complètes de d'Alembert* (Paris: Belin, 1821), vol. 1, pp. 17-99.

D'Alembert, Jean le Rond, *Preliminary Discourse to the Encyclopedia of Diderot*. Trans. Richard N. Schwab (Indianapolis: Bobbs-Merrill, 1963).

Thoughtful doing and early modern oeconomy

Ian Inkster

Technology is the knack of so arranging the world that we don't have to experience it.

Max Frisch, *Homo Faber* 1957 [San Diego, Harcourt, 1994]

In a society where ordinary citizens regarded slaves as their private property, those 'groupings of the commons' such as farmers or technicians who depended on handwork dwelt in another world. Advances in science and philosophy, even in classical mathematics and mechanics, had no impact on this social reality. Whilst the fit body was declared the best receptacle of the fit mind (Isocrates, 436-338), actual handwork was another matter entirely. Socrates argued that mechanical skills damaged the physique of those who practised them and impaired their minds; such supposed 'mechanical skills leave no free time for friends or politics'. In his *Politics,* Aristotle claimed that in the best governed state 'the citizens must not lead the life of mechanics or tradesmen, for such a life is ignoble and inimical to virtue'.[1] What chance was there that even potentially useful and reliable knowledge would be brought to bear on problems of material production? For the platonic philosopher the profession was sufficiently in the knowing.[2] In ancient Athens, the situation of knowledge and production techniques was multiply separate. Although the philosopher might conceivably pass the mechanician on the streets of Athens, there was little spatial, temporal, social or cognitive proximity between them. Because of this, philo knowledge was rarely brought to bear on technique in the classical world.

Surely the mind/hand distinction was never convincingly wrought unless it pointed to socio-spatial distinction as much as some sort of cultural logic.[3] The contemplative scholar on the hill is not the same as the scholar in the dockyard. This is not merely a matter of physical distance. In the dockyard the

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[1] Aristotle, *Politics*, trans. Benjamin Jowett (Oxford: Oxford University Press, 1921), part 7, 1328b-1329a; Xenophon, *Oeconomicus*, 4, 2-3, J. Ferguson and K. Chisholm, *Political and Social Life in the Great Age of Athens* (London: Ward Lock Educational, 1978), p. 93.

[2] Plato, *Phaedo*, trans. Benjamin Jowett (Oxford: Oxford University Press, 1953), 96a.

[3] Chun-yu (Jerry) Liu, *Comparative studies of european and Chinese cultural identity – a conceptual and historical approach* (PhD dissertation, Faculty of Arts and Humanities, The Nottingham Trent University, United Kingdom, 2002). See also see Takie S. Lebra, *The Japanese self in cultural logic* (Honolulu: University of Hawaii Press, 2004).

knowledge of the scholar has already been corrupted to (possible) practice, if only because of the manner in which it is about to be displayed and deployed. If this is so, then much of our enquiry must surely lie in the processes that bring the scholar into the dockyard in some places but not in others. This form of enquiry, at the most universal level, may be of greater importance to our entering into the past of industrialisation than disputes as to the precise character of the 'originally' reflective knowledge. Material impacts will not be felt from the mountain as such.

The notion of the 'mindful hand' problematises or challenges the above dichotomies and those highlighted by Peter Dear. The full mind may not be replete with what we then called or now call science. What we do know, I think, is that in many key points and sites some forms of useful and reliable knowledge were brought to bear on some forms of material production, artefact or process.[4] The unwashed artificer may not have been the philosophical engineer, but neither in most cases was he the unregulated empiricist. Folk may be guided into practice through some type of know-how, whether this be silently tacit or noisily recorded. The relations between inquiry and invention within Europe in the years prior to the fuller industrialisation of the nineteenth century are difficult to specify, and a great deal lies begging in the term 'brought to bear' – what sorts of mind assets were needed for technological change? How were such assets 'held' in the mind? How do we evaluate Simon Schaffer's formulation concerning the relation between contemplative knowledge of the created world and active transformation of its practical order? Often enough assimilation was within the mind/hands of one man. Bringing to bear did not necessarily signify a movement from one distinction to another, but a process of assimilation of the two within the one mind.

The essays in this collection taught me three things. It is good to write under the gift of an inspired and blessed rubric. It is possible to educate the wise in precise details even under the banner of such a catholic enterprise – before this I had known nothing of how drainage investors were awarded the commons and very little of why the pre-drained fenlands gained higher rents than surrounding dry lands. In addition, I find that it is always possible to improve and clarify by wider and more formal comparisons, either across time or across space, a theme to which I shall return.

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4 Ian Inkster, 'Potentially global: "useful and reliable knowledge" and material progress in Europe, 1474-1914,' *International history review* 28 (2006) 237-286. Here I also argue that excluding reliable knowledge from practical tinkering creates a false dichotomy whatever the historical context. The sole criticism that now remains of the brilliant early work of A.E. Musson and E. Robinson is that in its often empirically deft attempts to forge the science-practice relationship it tends to exaggerate the difference between the two notions: see A.E. Musson and Eric Robinson, *Science and technology in the Industrial Revolution* (Manchester: Manchester University Press, 1969).

In this book we meet all forms of knowledge – Useful, Scientific, Valuable, Tacit, Theoretical, Artisanal and Craft. I would suggest especially that we critically consider distinctions between artisanal and craft knowledge, as the latter term is normally meant, if only to problematise another doubtful dichotomy. The artisan is a person who may have a close understanding of craft, theoretical and scientific knowledge as represented outside his craft in books, maps and lecture courses, any of which he may bring to bear on a technical or instrumental problem. In turn, the object-solution of that problem may later serve formal scientific or reflective knowledge (as an instrument in an observation or experiment for instance) in a multitude of ways, within that site or elsewhere. Craft knowledge is normally construed as tacit knowledge accumulated through apprenticeship, guild regulations and associations, practice and observation, and master-works etc. and as bounded by the tools and machines, processes of production and organization, and products of an industry or related industries. At what point such knowledge transforms into artisanal (or later, engineering) knowledge may only be judged by examination of individuals, sites and collectivities in real detail, as in several of the essays of this collection.

The essays of this volume examine knowledge as represented in texts, scores, figures, maps, patterns, practices and objects. Knowledge of all sorts might be represented in each of these forms, except tacit, which may not be represented adequately by text – even the most practical and embracive manual may only be said to contain tacit knowledge when the user has by repetition mastered the tricks, pains and gimmicks involved in actual material manipulation, use of tools or instruments, sequencing and timing of micro-operations and so on. That is when he or she has practised and used or created objects.

We also have sites. We learn of sites in which regimes of useful and reliable knowledge appear as crucial resources and we seem to have also very variable proximities of knowledge (the knowledge that was brought to bear) to technique. The approach to the mindful hand through the contested sites of its endeavours seems to mark the style of this collection and distinguishes it from other recent approaches to the relations between knowledge (especially this thing called science) and technique.[5] The European sites of technical achievement were not merely organic growths, natural niches of a wider cultural tendency. They were often also forcefully constructed at key points with

[5] Margaret Jacob, *Scientific culture and the making of the industrial West* (New York: Oxford University Press, 1997); Jacob and Larry Stewart, *Practical matter. Newton's science in the service of industry and empire 1687-1851* (Cambridge, Mass.: Harvard University Press, 2004); Joel Mokyr, *Lever of riches* (New York: Oxford University Press, 1990); Mokyr, *The gifts of Athena. Historical origins of the knowledge economy,* (Princeton: Princeton University Press, 2002).

appropriate staging, and regulated and protected by those who profited from the applications of knowledge; the essays by Ashworth and Rosenband point to the depth and complexity of state influence over and penetration of creative sites. Just as black slaves were but pieces of men, skilled white men were pieces of the greater engine of manufacture.[6]

The notion of artisan 'knowledge' as a sort of handboy for real science conjures for me a parallel image of Mary Somerville [1780-1872] standing at the side of her less talented brother scrounging scraps of mathematical tutoring, perhaps giving a little, unacknowledged, in return. When we think within the dichotomy science/technology we are always in danger of invoking the image of an avuncular and suspect genteel science bending down with a gleam in its eye towards a potentially wayward technique. But, in our present enterprise we are presented far more often with forms of useful and reliable knowledge in specific sites, which conjures rather the idea of mindful but handy knowledge as that knowledge and insight which was brought to bear on technical endeavours of all kinds. Productive sites are full of instruments and skills, whether the mirrors and lenses or grinding and mathematical draughtsmanship of Paris in the 1620s, or the commercial knowledge and instrumental skills found within London instrument shops of the late 18th century. (Compare here the essays of Dijksterhuis and Bennett.)

They are also places where such assets are not only available to savants but help determine the character, strength and trajectory of productive outcomes. In such sites knowledge is not merely handed over from intellect to craft (the old quarrel over Joseph Black and James Watt springs to mind[7]) but the whole panoply of instrument, knowledge and skill is brought to bear upon problems of material production and knowledge creation in a purposeful yet indeterminate site-like manner. Out of which emerged the 'law' of sines of Descartes? Dijksterhuis describes this at one point as a 'collaborative effort in which these skills combined through these individuals'. In a site rich with assets of skill and instrumentation, a wave theory of light may be an unintended consequence of a telescope design project.

[6] Compare Simon Schaffer quoting Adam Ferguson in 1767 in his introduction to section four of this book and the *piexes de India* specified in the *asiento* licenses granted by Spain for slave supply from euro-traders from the 1570s; Ronald Segal, *The black diaspora* (London: Faber and Faber, 1994), pp. 17-27.

[7] See J.P. Muirhead, *The origin and progress of the mechanical inventions of James Watt* (London: J. Murray, 1854) volume 2; D. Fleming, 'Latent heat and the invention of the Watt engine,' *Isis* 43 (1952): 3-9; E. Robinson and D. McKie, *Partners in science: James Watt and Joseph Black* (London: Constable, 1970); Ian Inkster, 'Discoveries, inventions and industrial revolutions: on the varied contributions of technologies and institutions from an international historical perspective,' *History of technology* 18 (1996): 39-58.

Comparison engines, or the global view

It might be that we should rest very content with an approach that offers the possibility of generalisations across Europe. But the historical problems concerning the relations of knowledge to technique seem to be inherently global and potentially of central interest to all of us who wish to address the question of the material development of Europe/the West in the face of its previous seeming backwardness.[8] Under an older economistic positivism, the problem of the great bifurcation of the world could be addressed with reasonable certainty and solemnity, as hinted at here by Ashworth in his approach to the work of Walt Rostow.[9] There were measures of achievement such as income, nutrition or consumption per capita and they could be compared and their points of bifurcation located. There were models and data sets on capital formation, agricultural output, prices and interest rates and so on, and these too could be computed in order to find explanations. The comparison engines were in place, even if the historical research to fill in the datum blanks (the work of the engine) was often missing or lazy or loath to come forth.[10] A switch to the themes of culture – institution, knowledge and intellect, social interests and so on – cast all such comparisons into doubt. No longer could we refer to seemingly 'objective criteria' such as investment rates. Further, when the comparators centred upon cultural inputs to material progress, analytical weapons were soon sharpened and real meanings became convoluted. In essence, any program that utilises material on interests, institutions, instruments and knowledge as some type of explanation of the global bifurcation faces the problem of finding comparators that will not be immediately condemned as eurocentric and beyond the post-modern pale. But this need not deter us. With the present volume we do face the possibility that soon enough a new global history will meet a new social and cultural history of technology. In a variety of ways, the latter has begun to be applied to regions well beyond Europe.[11]

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[8] It might be noted that the most forthright of modern treatments emphasises Europe's backwardness into the late 18th century and makes short work of the importance of any unique generation or ownership of knowledge of science or technique when explaining the subsequent European victory; Andre Gunder Frank, *ReOrient: global economy in the Asian age* (Berkeley: University of California Press, 1998).

[9] K. Pomeranz, *The great divergence* (Princeton: Princeton University Press, 2000).

[10] For excellent reviews and judgements see Joel Mokyr, ed., *The British Industrial Revolution. An economic perspective* (Boulder, Colorado: Westview Press, 1993), chapters 1 and 5; Jan de Vries, 'Economic growth before and after the Industrial Revolution,' M. Prak ed., *Early modern capitalism. economic and social change in Europe 1400-1800* (London: Routledge, 2001), pp. 177-194; N. F.R. Crafts, 'The First Industrial Revolution: a guided tour for growth economists,' *American Economic Review* 86 (1996): 195-202.

[11] Stephen Hill, *The tragedy of technology* (London: Pluto Press, 1988); Ting-yee Kuo and Kwang-ching Liu, 'Self-strengthening: the pursuit of western technology,' John K. Fairbank, ed., *The Cambridge*

Several possible comparison engines strike one after reading the essays in this volume. Ones dealt with more or less in the present collection include mathematisation (its contingencies, character and function), instruments (their incidence and location) and skills (especially, perhaps, the materials to which they were applied). Intellectual or even mundane features of 'science,' such as controlled experimentation, may always be amongst the most problematic of comparators, but this is also the case for those seemingly more accessible and less-eurocentric aspects or engines of comparison. Thus skills may be in glass or metal but also in bamboo and paper, and their location may be disputable on both spatial and social grounds. Other aspects of skill might be more globally testable: the number and distribution of artisans, those whose expert hands were trained in experience and apprenticeship of some sort, is surely a feasible subject of critical enquiry. Were the sixty-two different professions of some 300,000 artisans recognised officially by the Chinese authorities in 1393 comparable with those of Europe or were they not? How many worked in metal and glass and how many understood gearing and belting?[12]

Skill migration is another obvious area for enquiry, particularly as to its relations with levels of persecution and acceptance of minority groups, whether carried by specifically expert craftsmen, or whether assisted by the recipient state. The ways in which secrecy is maintained or overcome within and between creative sites – the more developed the market forces of the society the more there seems to be an incentive towards secrecy, thus the need for some form of intellectual property rights – again appears to be of real importance. With ultimate secrecy we are back on the mountain-top. How did different historical systems resolve what appear to us moderns as the irreconcilables? The greater the speed of change, the greater the need for secrecy, but the lesser the likelihood of maintaining it. In contrast, sharing of either information or techniques within or between sites might be more likely where rewards are lower or achievement little or only tardily recognised. That is, significant behaviour within exemplary sites may at most times be contaminated

history of China 10, part 1 (Cambridge: Cambridge University Press, 1978), pp. 491-542; Nathan Sivin and John Zhang, 'Steam power and networks in China 1860-98,' *History of technology* 25 (2004): 203-10; Liu op. cit footnote 3; T. Umesao, James Bartholomew and Shigeharu Sugita eds., *Japanese civilization in the modern world: Vol. 10, Technology* (Kyoto: National Museum of Ethnology, 1998); Ian Inkster, *The Japanese industrial economy. Late development and cultural causation* (London: Routledge, 2001); M. Lackner and N. Vittinghoff eds., *Mapping meanings: the field of new learning in late Qing China* (Leiden: Brill Academic Publishers, 2004); B. Elman, *On their own terms: science in China 1550-1900* (Cambridge, MA: Harvard University Press, 2005).

[12] Jerry C.Y. Liu, 'Cultural logics for the regime of useful knowledge during the Ming and early Qing China c. 1400-1700,' The 9th Global Economic History Network Conference, LSE and Wenzao Ursuline College of Languages, 9-11 May 2006, Kaohsiung, Taiwan, 1-21.

by the commercial and political imperatives that lie beyond site, and not just by competitive interests, networks, skills and cultures of intent or constraint within site. Any or all such elements might become those of a comparative or more global approach to the history of technique and its relations with useful and reliable knowledge, even in cases where such knowledge might be unambiguously labelled 'science'.

A most ambitious task would be to take up at a comparative or global level the very notion of sites of endeavour, and there are several useful hints at how this might be done within the essays of the present book. Take the well-known European case of mathematicians as practical artificers counterpoised with Huygens-like genteel academical geometers, as addressed in Dijksterhuis' essay on dioptrics. A European perspective might view this as posing a problem for Europe. A global historian with knowledge of the far greater social divisions between mathematicians and natural scientists in Japan, China and elsewhere might spot the comparative European advantage. In places outside of Europe mathematicians and natural scientists would in all probability not enter the same site.[13] The global point is that, even where a truly reflective or academic mathematician were to be taken or mistaken as a mere artificer (for instance, because their creative mathematical work was exposed around the artefact of the pendulum clock), this did not mean in the Europe of the mid seventeenth century that he was excommunicated from the proximity of either practitioners or knowledge makers and carriers. He may be mal-defined amongst them, things might get awkward, but that would not frequently stop a creative site from working – it may merely mean that key individuals would become even more vigorous in public pursuit of success. In fact, Djksterhuis argues that in creative sites housing mathematics, the inquisitive and contemplative fused or interwove with the inventive and manipulative, as in dioptrics where the refractive effects of the telescope were explained or predicted in mathematical terms. So status distinctions were not based on such categories of activity but on the basis of ultimate goals. It was not so much that Huygens was a lens-grinder but that he used his mathematics to perfect telescopy as an ultimate goal that served to confuse his social status.

Relations or links between state authorities and creative sites appear as a potential global theme. We are advised here that there must be communication between sites, extending to movements of skill and artefact. But in any system in which skills or knowledge might frequently travel so too can authority and its injunctions, and these may be such as to inhibit novelty. The problem of

[13] For one excellent expression of the problem see James Bartholomew, *The formation of science in Japan* (New Haven: Yale University Press, 1989).

authority seems to loom especially in sites based on large, public goods technologies such as docks or irrigation schemes or at such places as customs and excise systems, at the very heart of fiscal-military states. Thus Simon Schaffer emphasises the close relations in such projects of technology, analysis, government regulation and the 'needs and the institutions of the military-fiscal state'. It would be of great interest to see how these elements configured in different cultural settings, returning in a cultural vehicle to some of the concerns of such institutionalists in development theory as Hirschman and Lindblom and their focus on co-ordination.[14] Perhaps mediations at times required a co-ordinated proximity – can this be found elsewhere than in Europe and coexistent with the liberal ameliorations of the 'system of terror' referred to by Ashworth? Mukerji points out the often-unclouded rationality of opposition to such great projects and shows that it could be based on a variety of elements. Her essay relates instances of a lack of confidence in the ability or motives of projectors, the potential or actual destruction of existing productive assets (which in the case of early modern canals or drainage systems might extend over a period of decades) and the loss of resources faced by local elites. At what point does the state step in, and how? Authority might well, as in several of our cases, harness useful and reliable knowledge to address such opposition. Technical demonstration or information could be used to foil almost anyone. Where a project had been designed and patronised by powerful bureaucrats and clerics who pursued strategies of demonstration and measurement and expert groupings, the high public visibility of experts and notables (the notable witnessing the field measurements was a 'show' that fused two acceptable sources of authority, designed to cement trust) was clearly organised to reduce rational resistance. Was this sort of forced solution to be found in major civil engineering projects in other parts of the world? If projects were often as not sites for decisions and knowledge accumulation, verification and modification, how did different regimes manage such processes to their advantage? With such civil engineering we do seem to have a 'public goods' situation for knowledge – projects are ahead of demand at great cost and possible large risk, and are thus not undertaken by the normal market-entrepreneurial nexus. If they are not state-run officially, then they certainly need state patronage – contracting, legal mechanisms and regulations

[14] A.O. Hirschman, *Development projects observed* (Washington DC: The Brookings Institution, 1967); John Waterbury, *Hydropolitics of the Nile Valley* (Syracuse: Syracuse University Press, 1979); A.O. Hirschman and Charles E. Lindblom, 'Economic development, research and development, policy making,' *Behavioural science* 7-8 (1967-8): 211-22; R.W. Rycroft and J.S. Szyliowics, 'The technological dimensions of decision making; the case of the Aswan High Dam,' *World politics* 33 (1980): 36-51.

are all required, and here a public display of seemingly authoritative knowledge was a requirement for most proponents or antagonists, and this was set within a tenuously elongated process. This seems quite different from the world of the mechanical engineering inventions of individual artisans and mechanicians but the distinction surely deserves serious comparative studies. Lissa Roberts does offer us a hint with her Britain-Netherlands contrast. Dutch universities in comparison to British were especially practical and technical, possibly just because Holland was dominated by a public goods technology that provoked public knowledge discourse and debate, so university expertise was called up more than was the case in the mechanical engineering, artisan traditions of Britain.

Finally and related, just how representative were creative technological sites? The Venetian dockyards did not represent ordinary Italian technique, neither did Henry the Navigator's famous observatory and school of navigation set-up at Sagres represent the normal congeries of talent and skill found in Portugal. It might nonetheless be recalled that these were principally assemblage technology sites, and of ultimate concern to governments. If the financing, patronage or legislative environ of the creative site is in the gift of a central political authority (however indirectly), does its consequent effectiveness as a place of industrial advancement require that it be sequestered, nurtured and deliberately bounded by walls that are fashioned in one way or another to separate it out from the surrounding regional or national cultural system, if only to minimise disturbance? Much has been written on just how *enclavist* or foreign such large-scale public goods sites were, whether those of Peter the Great in Russia or the arsenals of late nineteenth century China and Japan, and several essays in the present volume suggest the same within those areas of Europe associated with early modern scientific advances.[15] Did their undoubted absorption of high skills from everywhere in the globe, and their frequent use of displays of formalised useful and reliable knowledge as part and parcel of their local political and cultural persuasions create a mode of technological advancement that has coloured the perceptions of many historians and swept from view the more mundane sites of mechanical engineering endeavour in small, competitive and far more numerous and insidious artisan workshops?

[15] Compare essays here by Schaffer, Mukerji, Djksterhuis, Voss, Ash, Ashworth and Fleischer with material in T. Hashimoto, 'Introducing a French technological system: the origins and early history of the Yokosuka Dockyard,' *East Asian science, technology and medicine* 16 (1999): 53-72; Meng Yue, 'Hybrid science versus modernity: the practice of the Jiangnan Arsenal 1864-1897,' *EASTM* 16 (1999): 13-52; and for Russia, Ian Inkster, 'Technological and industrial change: a comparative essay' Roy Porter ed., *Eighteenth century science,* Vol. 4 of *The Cambridge history of science* (Cambridge: Cambridge University Press, 2003), pp. 845-881.

More interestingly, may the balance of these perspectives be redressed in a new global cultural history of technology based on the complete range of sites of endeavour?

Primary sources

Aristotle, *Politics* (trans. Benjamin Jowett, Oxford: Oxford University Press, 1921).
Plato, *Phaedo*, trans. Benjamin Jowett (Oxford: Oxford University Press, 1953).
Xenophon, *Oeconomicus*, J. Ferguson and K. Chisholm, *Political and Social Life in the Great Age of Athens* (London: Ward Lock Educational, 1978).

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Cumulative bibliography

Ackerman, James S., 'The involvement of artists in Renaissance science,' John W. Shirley and F. David Hoeniger, eds., *Science and the arts in the Renaissance* (Washington DC, Folger Books, 1985), pp. 94-129.

Adas, Michael, *Machines as the measure of men: science, technology and ideologies of western dominance* (Ithaca: Cornell University Press, 1989).

Adlung, Alfred, 'Alte apothekerfamilien und ihre apotheken,' *Pharmazeutische Zeitung* 73 (1928): 1453–1460.

Agar, Jon and Crosbie Smith, eds., *Making space for science: territorial themes in the shaping of knowledge* (Macmillan, 1998).

Agnew, Jean-Christophe, *Worlds apart: the market and the theater in anglo-American thought, 1550-1750* (New York: Cambridge University Press, 1986).

Ainsworth, Maryan W., 'Commentary: An integrated approach,' Maryan W. Ainsworth, ed., *Early Netherlandish painting at the crossroads. A critical look at current methodologies* (New Haven and London: Yale University Press, 2001): 106-121.

Alberts, Gerard, *Jaren van Berekening. Toepassingsgerichte initiatieven in de Nederlandse wiskunde-beoefening 1945-1960* (Amsterdam: Amsterdam University Press, 1998).

Alder, Ken, 'Making Things the Same: representation, tolerance and the end of the Ancien Regime in France,' *Social studies of science* 28 (1998): 499-545.

Alder, Ken, *Engineering the Revolution: arms and enlightenment in France 1763-1815* (Princeton: Princeton University Press, 1997).

Alexander, Amir, *Geometrical landscapes: the voyages of discovery and the transformation of mathematical practice* (Stanford: Stanford University Press, 2002).

André, Louis, *Machines à papier: innovation et transformations de l'industrie papetière en France, 1798-1860* (Paris: Éditions de l'école des hautes études en sciences sociales, 1996).

Ash, Eric H., *Power, knowledge, and expertise in Elizabethan England* (Baltimore: The Johns Hopkins University Press, 2004).

Ashby, Thomas, *The aqueducts of ancient Rome* (Oxford: Oxford University Press, 1930).

Ashworth, William J., "Between the trader and the public': British alcohol standards and proof of good governance,' *Technology and culture*, 42 (2001): 27-50.

Ashworth, William J., 'Practical Objectivity: The excise, state and production in eighteenth century England,' *Social epistemology*, 18 (2004): 177-93.

Ashworth, William J., 'System of terror: Samuel Bentham, accountability and dockyard reform during the Napoleonic wars,' *Social history* 23 (1998): 63-79.

Ashworth, William J., 'The calculating eye: Herschel, Babbage and the business of astronomy,' *British journal for the history of science* 27 (1994): 409-42.

Ashworth, William J., *Customs and excise: trade, production, and consumption in England, 1640-1845* (Oxford: Oxford University Press, 2003).

Baker, Keith, *Condorcet: from natural philosophy to social mathematics* (Chicago: Chicago University Press, 1975).

Balston, John, *The Whatmans and wove (vélin) paper: its invention and development in the west* (West Farleigh, Kent: J. N. Balston, 1998).

Balston, Thomas, *James Whatman, father and son* (London: Methuen, 1957).

Bambach, Carmen C., *Drawing and painting in the Italian Renaissance workshop. Theory and practice, 1300-1600* (Cambridge: Cambridge University Press, 1999).

Banbury, Philip, *Shipbuilders of the Thames and Medway* (Newton Abbott: David and Charles, 1971).

Barker, Peter and R. Goldstein, 'Is seventeenth-century physics indebted to the stoics?,' *Centaurus* 27 (1984): 148-164.

Barnes, Barry and Steven Shapin, 'Head and hand: rhetorical resources in British pedagogical Writing 1770-1850,' *Oxford review of education* 2 (1976): 231-254.

Barrell, John, *Imagining the king's death: figurative treason, fantasies of regicide, 1793-1796* (Oxford: Oxford University Press, 2000).

Barrington Partridge, R.C., *The history of the legal deposit of books throughout the British Empire* (London: The Library Association, 1938).

Bartholomew James, *The formation of science in Japan* (New Haven: Yale University Press, 1989).

Baxandall, Michael, 'Hubert Gerhard and the altar of Christoph Fugger: the sculpture and its making,' *Münchner jahrbuch der bildenden kunst*, ser. 3, vol 17 (1966): 127-144.

Becchetti, P. 'La Marrana dell' Acqua Mariana,' *Lunario Romano* 3 (1974): 15-41.

Becker, Peter and William Clark, eds., *Little tools of knowledge: historical essays on academic and bureaucratic practices* (Ann Arbor: University of Michigan Press, 2001).

Bedini, Silvio, 'Galileo and scientific instruments,' Ernan McMullin, ed., *Galileo man of science* (New York: Basic Books, 1967: 127-54.

Bedini, Silvio, *Thomas Jefferson and his copying machines* (Charlottesville: University Press of Virginia, 1984).

Beik, William, *Absolutism and society in seventeenth-century france: state power and provincial aristocracy in Languedoc* (Cambridge: Cambridge University Press, 1985).

Beisswanger, Gabriele, *Arzneimittelversorgung im 18. Jahrhundert: Die Stadt Braunschweig und die ländlichen Distrikte im Herzogtum Braunschweig-Wolfenbüttel* (Braunschweig: Dt. Apothekerverlag, 1968).

Beltrami, G., *Leonardo Bufalini e la sua pianta topographica di Roma* (Florence, 1880).

Bennet, James A., 'Hooke's instruments,' Jim Bennet et.al. eds., *London's Leonardo – the life and work of Robert Hooke* (Oxford: Oxford University Press, 2003), pp. 63-104.

Bennett, James A., 'Shopping for Instruments in Paris and London,' *Merchants and marvels: commerce, science, and art in early modern Europe*, eds., Pamela H. Smith and Paula Findlen (New York and London: Routledge, 2002), pp. 370-95.

Bennett, James A.. 'Wren's last building?,' *Notes and records of the Royal Society of London* 27 (1972):107-18.

Berg, Maxine and Helen Clifford, eds., *Consumers and luxury: consumer culture in Europe 1650-1850* (Manchester: Manchester University Press, 1999).

Berg, Maxine and Kristine Bruland, eds., *Technological revolutions in Europe: historical perspectives* (Cheltenham: Edward Elgar, 1998).

Berg, Maxine, 'From imitation to invention: creating commodities in eighteenth-century Britain,' *Economic history review* 55 (2002): 1-30.
Berg, Maxine, 'In pursuit of luxury: global history and British consumer goods in the eighteenth century,' *Past and present* 182 (2004): 87-141.
Berg, Maxine, 'New commodities, luxuries and their consumers in eighteenth-century England,' Maxine Berg and Helen Clifford, eds., *Consumers and luxury*, pp. 63-85.
Berg, Maxine, *The age of manufactures 1700-1820* (London: Fontana, 1985).
Berg, Maxine, *The machinery question and the making of political economy 1815-1848* (Cambridge: Cambridge University Press, 1980).
Bergasse, Jean-Denis *Le Canal du Midi* (Cessenon: J.-D. Bergasse,1985-6).
Bergvelt, Ellinoor and Renée Kistemaker, eds., *De wereld binnen handbereik, Nederlandse kunst- en rariteitenverzamelingen, 1585-1735* (Zwolle: Waanders, 1992).
Berman, Morris, *Social change and scientific organization: the Royal Institution 1799-1844* (London: Heinemann, 1978).
Bernal, J. D., *Science in history* (London: Watts, 1954).
Bewer, Francesca G., 'The sculpture of Adriaen de Vries: a technical study,' Debra Pincus, ed., *Small bronzes in the Renaissance* (Washington, DC: Centre for Advanced Study in the Visual Arts, 2001), p. 159-193.
Bezemer Sellers, Vanessa, *Courtly gardens in Holland 1600-1650, the House of Orange and the Hortus Batavus* (Amsterdam: Architectura & Natura Press, 2001).
Biagioli, Mario, 'Replication or monopoly? the economies of invention and discovery in Galileo's observations of 1610,' *Science in context* 13 (2000): 547-592.
Bicker Caarten, A., *Middeleeuwse watermolens in Hollands polder 1407/'08 rondom 1500* (Wormerveer: Stichting Uitgeverij Noord-Holland, 1990).
Bijker, Wiebe E. 'Sociohistorical technology studies,' S. Jasanoff, G.E. Markle, J.C. Petersen and T. Pinch, eds., *Handbook of science and technology studies*, (Thousand Oaks, London, New Delhi: Sage Publications, 1995): 229-256.
Blair, Ann, 'Humanist methods in natural philosophy: the commonplace book,' *Journal of the history of ideas* 53 (1992): 535-539.
Boesch, Hans, ed., 'Urkunden und auszüge aus dem Archiv und der Bibliothek des Germanischen Museums in Nürnberg,' *Jahrbuch der kunsthistorischen Sammlungen der allerhoechsten Kaiserhauses*, 7 (1888): lxxxvii-xc.
Boncompain, J., *La révolution des auteurs: naissance de la propriété intellectuelle (1773-1815)* (Paris: Fayard, 2001).
Booker, Peter, *History of engineering drawing* (London: Chatto and Windus, 1963).
Boorsch, Suzanne, "Fireworks on paper: celebration of the 'Glorious Peace', London 1814,' *Art on paper* 4 (2000): 54-59.
Borger, G.J., 'De Beemster – ideaal of compromis,' R.M. van Heeringen, E.H.P. Cordfunke, M.Ilsink and H. Sarfatij, eds., *Geordend landschap, 3000 jaar ruimtelijke ordening in Nederland*, (Hilversum: Verloren 2004): 75-102.
Borkenau, Franz, 'Zur Soziologie des mechanistischen Weltbildes,' *Zeitschrift für Sozialforschung* (1932): 311-335, translated in *Science in context* 1 (1987): 109-27.
Bos, Henk, *Lectures in the history of mathematics* (New York: American Mathematical Society, 1993).
Bosher, J. F., *The single duty project: a study of the movement for a French customs union in the eighteenth century* (London: Athlone Press, 1969).

Botton, Alain de, *The art of travel* (London: Penguin, 2002).
Bowden, William, 'The influence of the manufacturers on some of the early policies of William Pitt,' *American history review* 19 (1924): 655-74.
Bowden, William, 'The English manufacturers and the commercial treaty of 1786 with France,' *American history review* 25 (1919): 18-35.
Bowden, William, *Industrial society in England towards the end of the eighteenth-century* (London: Frank Cass, 1925, 2nd edn., 1965).
Brewer, John and Porter, Roy eds., *Consumption and the world of goods* (London: Routledge, 1993).
Brewer, John, *The sinews of power: war, money and the English state 1688-1783* (London: Unwin, Hyman, 1989).
Briscoe, Norris A., *Economic policy of Walpole* (New York: Columbia University Press, 1907).
Brock, Alan St. Hill, *Pyrotechnics: the history and art of firework making* (London: Daniel O'Connor, 1922).
Broman, Thomas H., 'The Habermasian public sphere and 'science 'in' the Enlightenment,' *History of science* 36 (1998): 123-149.
Brose, Eric Dorn, *The politics of technological change in Prussia 1809-1848* (Princeton: Princeton University Press, 1993).
Bryce, Judith, 'Cosimo Bartoli's *Del modo di misurare le distanze* (1564): A reappraisal of his sources,' *Annali dell'Istituto e Museo di Storia della Scienza Firenze* (1980): 19-33.
Buchanan, P., and B. Gee, 'Inside the shop of an eighteenth century Optician,' *Bulletin of the Scientific Instrument Society* 82 (2004):10-15.
Buisman, J. *Duizend jaar weer, wind en water in de Lage Landen, 1575-1675* (Franeker: Uitgeverij Van Wijnen, 2000).
Buisseret, David, *The mapmakers' quest: depicting new worlds in Renaissance Europe* (Oxford: Oxford University Press, 2003).
Bukharin, N. I., et al, *Science at the cross roads* (London: Frank Cass, 1971 (1931)).
Bundock, Clement, *The story of the national union of printing, bookbinding and paper workers* (Oxford: Oxford University Press, 1959).
Burke, Peter, *A social history of knowledge: from Gutenberg to Diderot* (Cambridge: Polity Press, 2000).
Burnett, John, 'The history of adulteration in Great Britain in the nineteenth century, with special reference to bread, tea and beer' (unpublished PhD thesis: London School of Economics, 1958).
Burnett, John, *Plenty and want: a social history of diet in England from 1815 to the present day* (Harmondsworth: Penguin, 1968).
Butterfield, Herbert, *The origins of modern science 1300-1800* (New York: Free Press, 1965 (1949)).
Buxton, H.W., *Memoir of the life and labours of the late Charles Babbage, Esq., FRS*, ed., A. Hyman (Cambridge, MA: MIT Press, 1988).
Callon, Michel, 'An essay on framing and overflowing: economic externalities revisited by sociology,' Michel Callon ed., *The laws of the markets*, 244-269.
Cameron, Rondo, 'A new view of European industrialisation,' *Economic history review* 38 (1985): 1-23.
Campbell, Lorne, Susan Foister, and Ashok Roy, 'The methods and materials of Northern European painting, 1400-1550,' *National Gallery technical bulletin*, 18 (1997): 6-55.
Campbell-Kelly, M., ed., *The history of mathematical tables: from Sumer to spreadsheets* (Oxford: Oxford University Press, 2003).
Carlo Pedretti, *Leonardo Da Vinci: the Codex Hammer, formerly the Codex Leicester*, Catalogue by J. Roberts, (London: Royal Academy of Arts, 1981).

Carroll, Patrick 'Science, power, bodies: the mobilization of nature as state formation,' *Journal of historical sociology* 9 (1996): 139-167.

Carroll-Burke, Patrick, 'Tools, instruments and engines,' *Social studies of science* 31 (2001): 593-625.

Cartwright, Nancy, *The dappled world: a study of the boundaries of science* (Cambridge: Cambridge University Press, 1999).

Castalia, countess Granville, ed., *Lord Granville Leveson Gower (first earl Granville): private correspondence, 1781 to 1821*, 2 vols. (London: John Murray, 1916).

Chadarevian, Soraya de and Nick Hopwood, eds., *Models: the third dimension of science* (Stanford: Standford University Press, 2004).

Chandler, Dean, and A. Douglas Lacey, *The rise of the gas industry in Britain* (London: British Gas Council, 1949).

Chapman S. D., *The cotton industry in the Industrial Revolution* (London, 1972).

Chartier, Roger, *l'Ordre des Livres: lecteurs, auteurs, bibliothèques en Europe entre xiv^{e} et xviii^{e} siècle* (Paris: Alinea, 1992).

Clark, William, 'The misogyny of scholars,' *Perspectives on science* 1 (1993): 342-357.

Clark, William, 'The scientific revolution in the German nations,' Roy Porter and Mikuláš Teich, eds., *The scientific revolution in national context* (Cambridge: Cambridge University Press, 1992), 90-114.

Clercq, Peter de, 'Science at court: the eighteenth-century cabinet of scientific instruments and models of the Dutch Stadtholders,' *Annals of science* 45 (1988): 113-152.

Clercq, Peter de, *At the sign of the Oriental Lamp. The Musschenbroek workshop in Leiden, 1660-1750* (Rotterdam: Erasmus Publishing, 1997).

Clercq, Peter de, *Het koperen kabinet: schatkamers van de wetenschap, 1550-1950* (Leiden: Museum Boerhaave, 1994).

Clercq, Peter de, *The Leiden cabinet of physics* (Leiden: Museum Boerhaave, 1989).

Clifford, Helen, 'The king's arms and feathers'. A case study exploring the networks of manufacture operating in the London goldsmiths' trade in the eighteenth century,' David Mitchell, ed., *Goldsmiths, silversmiths and bankers: innovation and the transfer of skill 1550 to 1750.* Centre for metropolitan history, working paper series, No. 2 (London: Alan Sutton Publishing Ltd and Centre for Metropolitan History, 1995): 84-95.

CNRS, *Histoire de l'administration Française, Les Eaux et Forêts du 12^{e} au 20^{e} siècle* (Paris: Editions CNRS, 1987).

Coad, Jonathan, *The Royal Dockyards 1690-1850* (Aldershot: Scolar Press, 1989).

Coates-Stephens, Robert, 'The walls and aqueducts of Rome in the early middle ages, A.D. 500-1000,' *Journal of Roman studies* 88 (1998): 171-76.

Coffin, David, *Gardens and gardening in Papal Rome* (Princeton: Princeton University Press, 1991).

Cohen, I. Bernard, *Franklin and Newton* (Philadelphia: American Philosophical Society, 1956).

Cole, Michael, *Cellini and the principles of sculpture* (Cambridge: Cambridge University Press, 2002).

Coleman, D. C., 'Premiums for paper: The society and the early paper industry,' *Journal of the Royal Society of Arts* 107 (1959), 361-365.

Coleman, D. C., *The British paper industry, 1495-1860: a study in industrial growth* (Oxford: Clarendon Press, 1958).

Collins, Brenda and Ollerenshaw, Philip, eds., *The European linen industry in historical perspective* (Oxford: Oxford University Press, 2003).

Concina, Ennio, *L'arsenale della Republica de Venezia* (Milan: Electa, 1984).

Concina, Ennio, *Navis: l'umanesimo sul mare* (Turin: Einaudi, 1990).
Conseil d'Architecture, d'Urbanisme et de l'Environment de la Haute-Garonne, *Canal Royal de Languedoc: le partage des eaux* (Caue: Loubatières, 1992).
Cook, Harold J., 'The new philosophy in the Low Countries,' R. Porter and M. Teich, eds., *The Renaissance in national context* (Cambridge: Cambridge University Press, 1992), 115-149.
Cooper, Carolyn, 'The Portsmouth system of manufacture', *Technology and culture* 25 (1984): 182-225.
Cosgrove, Dennis, 'Review of Edmund C. Penning-Rowsell and David Lowenthal, eds., *Landscape, meanings and value*,' *Transactions of the Institute of British Geographers* 12 (1987): 369.
Crafts N.F.R., 'The first Industrial Revolution: A guided tour for growth economists,' *American economic review* 86 (1996): 195-202.
Cronon, William, *Nature's Metropolis* (New York: W. W. Norton, 1991).
Cummings, A. J. G. and Larry Stewart, 'The case of the eighteenth-century projector: entrepreneurs, engineers, and legitimacy at the Hanoverian Court,' in *Patronage and institutions: science, technology and medicine at the European Court, 1500-1750*, Bruce T. Moran, ed., (New York: Boydell Press, 1991), 235-261.
Cunningham, Andrew and Perry Williams, 'De-centring the 'big picture': the origins of modern science and the modern origins of science,' *British journal for the history of science*, 26 (1993): 407-432.
D'Onofrio, Cesare, *Le Fontane di Roma* (Rome: Roma Società, 1986).
Dagnall, H., *The taxation of paper in Great Britain, 1643-1861: a history and documentation* (Queensbury: In collaboration with The British Association of Paper Historians, 1998).
Dainville, François de, *Cartes Anciennes du Languedoc xvi^{e}-xviii^{e} S.* (Montpellier, Société Languedocienne de Géographie, 1961).
Daniels, Stephen, 'Loutherbourg's chemical theatre: Coalbrookdale by Night,' John Barrell, ed., Painting and the politics of culture: new essays on British art, 1700-1850 (Oxford: Oxford University Press, 1992).
Dann, Georg Edmund, 'Deutsche Apothekerfamilien: die Familien Marggraf und Blell,' *Pharmazeutische Zeitung* 82 (1937): 337-342.
Dann, Georg Edmund, 'Marggraf-Briefe,' *Geschichte der Pharmacie* 20 (1968): 20-22.
Dann, Georg Edmund, *Martin Heinrich Klaproth* (1743-1817) (Berlin: Akademie-Verlag, 1958).
Danner, Helga, *Van water tot land, van land tot water; verwikkelingen bij de indijking van de Beemster* (Wormerveer: Kunstdrukkerij Mercurius, 1987).
Darby, H. C., *The draining of the Fens* (Cambridge: Cambridge University Press, 1956).
Darby, H. C., *The medieval Fenland* (Cambridge: Cambridge University Press, 1940; 2nd ed., Newton Abbot, Devon: David & Charles, 1974).
Darnton, Robert, *Mesmerism and the end of the Enlightenment in France* (Cambridge, mass.: Harvard University Press, 1968).
Darnton, Robert, *The forbidden best-sellers of pre-revolutionary France* (London: Fontana Press, 1997).
Darnton, Robert, *The Great Cat Massacre, and other episodes in French cultural history* (London: Allen Lane, 1984).
Daunton, Martin J., *Progress and poverty: an economic history of Britain 1700- 1850* (Oxford: Oxford University Press, 1995).
Davids, C.A., 'Universiteiten, illustre scholen en de verspreiding van technische kennis in Nederland, eind 16^{e} – begin 19^{e} eeuw,' *Batavia academica* VIII (1990): 3-34.
Davis, Ralph, 'The rise of protection in England, 1689-1786,' *Economic history review* 19 (1966): 306-317.

Davis, Robert C., *Shipbuilders of the Venetian Arsenal* (Baltimore: Johns Hopkins University Press, 1991).

Dear, Peter, 'A mechanical microcosm: bodily passions, good manners and Cartesian mechanism,' Steven Shapin and Christopher Lawrence, eds., *Science incarnate* (Chicago: University of Chicago Press, 1998): 51-82.

Dear, Peter, 'What is the history of science the history *of*? Early modern roots of the ideology of modern science,' *Isis* 96 (2005): 390-406.

Dear, Peter, *Discipline and experience: the mathematical way in the Scientific Revolution* (Chicago: University of Chicago Press, 1995).

Dear, Peter, *Revolutionizing the sciences: European knowledge and its ambitions, 1500-1700* (Princeton, NJ: Princeton University Press, 2001).

Dear, Peter, *The intelligibility of nature: how science makes sense of the world* (Chicago: University of Chicago Press, 2006).

Defrance, M. Eugene, *Histoire de l'éclairage des rues de Paris* (Paris: Imprimerie Nationale, 1904).

Delph, Ronald, 'From Venetian visitor to Curial humanist: the development of Agostino Steuco's 'counter-Reformation thought',' *Renaissance quarterly* 47 (1994): 102-139.

Delph, Ronald, '*Renovatio, reformatio*, and Humanist ambition in Rome,' in R. Delph, M. Fontaine, and J. Martin, eds., *Heresy and religion in the culture of early modern Italy* (Kirksville: Truman State University Press, forthcoming 2006).

Dennis, Michael Aaron, 'Echoes of the past: Henry Guerlac and radar's historiographic problem,' Oskar Blumtritt, ed., *Tracking the history of Radar* (Piscataway, NJ: IEEE, 1994).

Dennis, Michael Aaron, 'Historiography of science: an American perspective,' John Krige and Dominique Pestre, ed., *Science in the twentieth century* (Amsterdam: Harwood Academic Publishers, 1997).

Dent, Robert K., *Old and new Birmingham, a history of the town and its people* (Birmingham, 1880).

Detienne, Marcel and Jean-Pierre Vernant, *Cunning intelligence in Greek culture and society* (Hassocks: Harvester, 1978).

Deveze, Michel, *La grande réformation des forêts royales sous Colbert, 1661-1680; une admirable réforme administrative* (Nancy: École Nationale des Eaux et Forêts, 1962).

Dietz, Vivian E., 'Before the age of capital: manufacturing interests and the British state, 1780-1800' (unpublished Ph.D. thesis: Princeton University, 1991).

Dijksterhuis, E.J., *The mechanization of the world picture* (1950; Princeton: Princeton University Press, 1986).

Dijksterhuis, Fokko Jan, *Lenses and waves. Christiaan Huygens and the mathematical science of optics in the seventeenth century* (Dordrecht: Kluwer Academic Publishers, 2004).

Dillen, J.G. van, *Van rijkdom en regenten, handboek tot de economische en sociale geschiedenis van Nederland tijdens de Republiek* (Den Haag: Martinus Nijhoff, 1970).

Dixon Hunt, John, 'Curiosities to adorn cabinets and gardens,' O. Impey and A. MacGregor, eds., *The origins of museums, the cabinet of curiosities in 16th and 17th-century Europe* (Oxford: Clarendon Press, 1985): 193-203.

Dixon Hunt, John, *Gardens and the picturesque, studies in the history of landscape architecture* (Cambridge, MA: MIT Press, 1992).

Dobbs, B.J.T. and Margaret Jacobs, *Newton and the culture of Newtonianism* (Antlantic Highlands, N.J.: Humanities Press, 1995).

Dobson, C. R., *Masters and journeymen: a prehistory of industrial relations, 1717-1800* (London: Croom Helm, 1980).

Doering, Oscar, 'Des Augburger patriciers Philipp Hainhofer beziehungen zum Herzog Philipp II von Pommern-Stettin. Correspondenzen aus den jahren 1610-1619,' *Quellen-*

schriften für kunstgeschichte und kunsttechnik des mittelalters und der neuzeit, NF Bd. 6 (Vienna: Carl Graeser, 1894): 74-112.
Dolan, Brian, *Josiah Wedgwood, entrepreneur to the Enlightenment* (London: Harper Collins, 2004).
Donaghay, M., 'Calonne and the Anglo-French Treaty of 1786,' *Journal of modern history* 50 (1978): D1157-D1184 (supplement – issue 3).
Donaghay, M., 'The exchange of products of the soil and industrial goods in the Anglo-French commercial Treaty of 1786,' *Journal of European economic history* 19 (1990): 377-401.
Dooley, A.C., *Author and printer in Victorian England* (Charlottesville: University Press of Virginia, 1992).
Dormer, Peter, ed., *The culture of craft: status and future* (Manchester: Manchester University Press, 1997).
Dormer, Peter, *The art of the maker: skill and its meaning in art, craft and design* (London: Thames and Hudson, 1994).
Drake, Stillman, 'Galileo in English literature of the seventeenth century,' Ernan McMullin, ed., *Galileo man of science* (New York: Basic Books, 1967), pp. 413-431.
Drake, Stillman, *Galileo at work: his scientific biography* (Chicago: Chicago University Press, 1978).
Drayton, Richard, *Nature's government: science, imperial Britain and the improvement of the world* (New Haven: Yale University Press, 2000).
Dutton, H. I., *The patent system and inventive activity during the Industrial Revolution, 1750-1852* (Manchester: Manchester University Press, 1984).
Edgerton, David, 'From innovation to use: ten (eclectic) theses on the history of technology,' *History and technology* 16 (1999): 1-26.
Eeghen, I.H. van, 'Van Warmoestraat naar Herengracht,' *Amstelodamum, maandblad voor de kennis van Amsterdam* 61 (1974): 97-102.
Egmond, Florike, 'Natuurlijke historie en savoir prolétaire,' Florike Egmond, Eric Jorink and Rienk Vermij, eds., *Kometen, monsters en muilezels. Het veranderende natuurbeeld en de natuurwetenschap in de zeventiende eeuw* (Haarlem: Uitgeverij Arcadia, 1999): 53-71.
Ehrman, John, *The British Government and Commercial Negotiations with Europe, 1783-1793* (Cambridge: Cambridge University Press, 1962).
Ehrman, John, *The younger Pitt: the years of Acclaim* (London: Constable & Co., 1969).
Elias, Johan E., *De vroedschap van Amsterdam, 1578-1795* (Haarlem: Loosjes, 1903-1905).
Elman B, *On their own terms: science in China 1550-1900* (Cambridge, MA: Harvard University Press, 2005).
Elton, Sir Arthur, 'Gas for light and heat,' Charles Singer, E. J. Holyard, A. R. Hall, and Trevor I. Williams, eds., *A history of technology*, 8 vols. (Oxford: Clarendon Press, 1954-84), vol. 4, *The Industrial Revolution, 1750-1850* (Oxford: Clarendon Press, 1958): 258-276.
Engel, Britta, 'Das Berliner akademielaboratorium zur zeit Marggrafs und Achards,' *Mitteilungen* (herausgegeben von der Fachgruppe 'Geschichte der Chemie' in der Gesellschaft Deutscher Chemiker) 13 (1997): 3-12.
Engerman, Stanley L., 'Mercantilism and overseas trade, 1700-1800,' in R. Floud and D. McCloskey eds., *The economic history of Britain* (Cambridge: Cambridge University Press, 2nd edn., 1995): 182-204.
Epstein, S. R., 'Craft guilds, apprenticeship, and technological change in preindustrial Europe,' *The Journal of Economic History* 58 (1998): 684–713.
Epstein, S.R., 'Journeymen, mobility and the circulation of technical knowledge, 14th-18th centuries,' Liliane Hilaire-Pérez and Anne-Françoise Garçon, eds., *Les chemins de la nouveauté: inventer, innover au regard de l'histoire* (Paris: CTHS, 2004): 411-430.
Erdman, David, *Blake: prophet against empire*, 3rd ed., (Princeton: Princeton UP, 1977).

Escosura, Leandro Prados de la, ed., *Exceptionalism and industrialisation: Britain and its European rivals, 1688-1815* (Cambridge: Cambridge University Press, 2004).

Evans, Harry, *Water distribution in ancient Rome; the evidence of Frontinus* (Ann Arbor: University of Michigan Press, 1994).

Everard, Stirling, *The history of the Gas Light and Coke Company, 1812-1949* (London: Ernest Benn, 1949).

Falkus, M. E., 'The early development of the British gas industry, 1790-1815,' *The economic history review* 35 (1982): 217-234.

Fara, Patricia, *Newton: the making of genius* (London: Macmillan, 2002).

Faries, Molly, 'Reshaping the field: the contribution of technical studies,' in Maryan W. Ainsworth, ed., *Early Netherlandish painting at the crossroads. A critical look at current methodologies* (New Haven and London: Yale University Press, 2001), pp. 70-105.

Farrington, Benjamin, *Francis Bacon: philosopher of industrial science* (London: Lawrence and Wishart, 1951).

Farrington, Benjamin, *Head and hand in ancient Greece: four studies in the social relations of thought* (London: Watts, 1947)

Favaro, Antonio, 'Due Lettere Inedite di Guidobaldo del Monte a Giacomo Contarini,' *Atti del Reale Istituto Veneto di Scienze, Lettere, ed Arti* LIX (1899-1900): 303-312.

Favaro, Antonio, *Galileo Galilei e lo Studio di Padova*, vol. II. (Padua: Antenore, 1966).

Fea, Carlo, *Storia delle acque antiche sorgenti in Roma* (Rome, 1832).

Feather, J., *Publishing, piracy, and politics: an historical study of copyright in Britain* (London: Mansell, 1994).

Ferguson, Niall, *Empire: the rise and demise of the British world order and the lessons for global power* (New York: Basic Books, 2003).

Findlen, Paula and Pamela Smith, eds., *Merchants and marvels: commerce, science and art in early modern Europe* (London: Routledge, 2002).

Findlen, Paula, *Possessing nature* (Berkeley, Los Angeles, London: University of California Press, 1994).

Fine, Arthur, *The shaky game: Einstein, realism and the quantum theory* (Chicago: University of Chicago Press, 1986).

Fleming D., 'Latent heat and the invention of the Watt engine,' *Isis* 43 (1952): 3-9.

Fogel, Michèle, *Les cérémonies de l'information dans la France du XVI^e^ au XVIII^e^ siècle* (Paris: Fayard, 1989).

Fortier, Bruno and Alain Demangeon, Alain, *Les vaisseaux et les villes* (Liège: Mardaga, 1978).

Forward, E.A., 'Simon Goodrich and his work as an engineer: II', *Transactions of the Newcomen Society* 18 (1937): 1-27.

Frank, Andre Gunder, *ReOrient: global economy in the Asian age* (Berkeley: University of California Press, 1998).

Frankenburger, Max, ed., *Beiträge zur geschichte Wenzel Jamnitzers und seiner familie. Studien zur deutschen kunstgeschichte,* Heft 30 (Strassburg: Heitz, 1901; Fasc. Repr. Nendeln/Liechtenstein: Kraus Reprint, 1979).

Franklin, John, *Navy board ship models 1650-1750* (Conway: Maritime Press, 1989).

Frosini, Pietro, *Il Tevere: le inondazione di Roma* (Rome: Accademia, 1977).

G.E.Fussell, *Crop nutrition: science and practice before Liebig* (Lawrence, Ka.: Coronado Press, 1971).

Gabriele Beisswanger, *Arzneimittelversorgung im 18. Jahrhundert: die Stadt Braunschweig und die ländlichen Distrikte im Herzogtum Braunschweig-Wolfenbüttel* (Braunschweig: Dt. Apothekerverlag, 1968).

Gambles, Anna, *Protection and politics: conservative economic discourse, 1815-1852* (Suffolk: Boydell and Brewer, 1999).
Gaukroger, Stephen, *Descartes. An intellectual biography* (Oxford: Clarendon Press, 1995).
Gazel, Henri, *Les anciens ouvriers papetiers d'Auvergne* (Clermont-Ferrand: A. Dumont, 1910).
Gelder, Hermann, 'Zur geschichte der (vormals königlichen) hofapotheke zu Berlin,' *Apotheker-Zeitung* 40 (1925): 1364-1367.
Gelderblom, Arie Jan, *Mannen en maagden in Hollands tuin; interpretatieve studies van Nederlandse letterkunde 1575-1781* (Utrecht: Rijksuniversiteit Utrecht, 1991).
Gelderblom, Oscar, 'The governance of early modern trade: the case of Hans Thijs, 1556-1611,' *Enterprise & society* 4 (2003): 606-39.
Gerschenkron, Alexander, *Economic backwardness in historical perspective: a book of essays* (Cambridge, MA: Belknap Press, 1962).
Geyer, Albert, 'Die räumlichkeiten der königlichen hofapotheke im Berliner Schloß,' *Hohenzollern-Jahrbuch* (1898): 227-230.
Gibbons, Michael, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott and Martin Troy, *The new production of knowledge: the dynamics of science and research in contemporary societies* (London: Sage, 1994).
Giere, Ronald N., *Science without laws* (Chicago: University of Chicago Press, 1999).
Gillispie, Charles Coulton, *Science and polity in France at the end of the Old Régime* (Princeton: Princeton University Press, 1980).
Glacken, Clarence J., *Traces on the Rhodian shore, nature and culture in western thought from ancient times to the end of the eighteenth century* (Berkeley: University of California Press, 1984).
Glaudemans, Marc, *Amsterdams Arcadia, de ontdekking van het achterland* (Nijmegen: SUN, 2000).
Golinski, Jan, 'The care of the self and the masculine birth of science,' *History of science* 40 (2002): 1-21.
Golinski, Jan, *Science as public culture: chemistry and enlightenment in Britain 1760-1820* (Cambridge: Cambridge University Press, 1992).
Gooding, David, 'In nature's school': Faraday as an experimentalist,' David Gooding, & Frank James, eds., *Faraday rediscovered*, (New York: Macmillan, 1985), pp. 104-135.
Gottschalk, Jürgen, 'Technische Verbesserungsvorschläge im Oberharzer Bergbau,' Erwin Stein and Albert Heinekamp, ed., *Gottfried Wilhelm Leibniz*, (Hannover: Schlüter, 1990), pp. 62-71.
Grafton. A and Jardine, L., ''Studied for action': how Gabriel Harvey read his livy,' *Past and present* 129 (1990): 30-78.
Grandin, Karl, Nina Wormbs and Sven Widmalm, eds., *The science-industry nexus: history, policy, implications* (New York: Watson, 2005).
Greenhill, Basil, *The evolution of the wooden ship* (London: Batsford, 1988).
Gregory, D., *The colonial present* (Oxford: Oxford University Press, 2004).
Grendler, Marcella, 'A Greek collection in Padua: the library of Gian Vincenzo Pinelli (1535-1601),' *Renaissance quarterly 33* (1980): 386-416.
Griffith, Richard, *Industrial retardation in the Netherlands, 1830-1850* (Den Haag: Martinus Nijhoff, 1979).
Griffiths, John, *The third man, the life and times of William Murdoch, 1754-1839, The inventor of gas lighting* (London: Andre Deutsch, 1992).
Grijzenhout, Frans, 'Wandelingen door Hollands Arkadia,' *De achttiende eeuw* 36 (2004): 132-142.
Grove, Richard, 'Indigenous knowledge and the significance of south-west India for Portuguese and Dutch constructions of tropical nature,' R.H.Grove, V. Damodaran and S. Sangwan, ed.,

Nature and the orient: the environmental history of south and southeast Asia, (New Delhi: Oxford University Press, 1998), pp. 187-209.
Gruber, Alain-Charles, "Les 'Vauxhalls' Parisiens au XVIII^{e} siècle,' *Bulletin de la Société de l'histoire de l'art français* (1972): 125-143.
Grünhagen, Konrad, *Über den bau und die einrichtung von apotheken in alter und neuer zeit* (Würzburg: Konrad Triltsch, 1939).
Haas, J.M., *A management odyssey: the Royal Dockyards 1714-1914* (Lanham: University Press of America, 1994).
Habermas, Jürgen, *The structural transformation of the public sphere: an inquiry into a category of Bourgeois society,* trans. Thomas Berger (Cambridge, MA: MIT Press, 1989 (1962)).
Habermas, Jürgen, *The theory of communicative action*, 2 vols., trans. Thomas McCarthy (Boston: Beacon Press, 1984).
Hacking, Ian, *Representing and intervening: introductory topics in the philosophy of natural science* (Cambridge: Cambridge University Press, 1983).
Hackmann, Willem, 'Scientific instruments: models of brass and aids to discovery,' David Gooding, Trevor Pinch and Simon Schaffer, eds., *The uses of experiment* (Cambridge: Cambridge University Press, 1989), pp. 31-65.
Haddon, Richard W., *On the shoulders of merchants: exchange and the mathematical conception of nature in early modern Europe* (Albany: SUNY Press, 1997).
Hahn, Roger, 'Science and the arts in France: the limitations of an encylopedic ideology,' *Studies in eighteenth-century culture* 10 (1981): 77-93.
Hahn, Roger, *L'hydrodynamique au XVIII^{e} siècle: aspects scientifiques et sociologiques* (Paris: Palais de la Découverte, 1965).
Hall, A. R., *Ballistics in the seventeenth century* (Cambridge: Cambridge University Press, 1952).
Hall, A.R., 'Architectura navalis,' *Transactions of the Newcomen Society* 51 (1979-80): 157-73.
Hammond P. W. and Egan, Harold, *Weighed in the balance: a history of the laboratory of the government Chemist* (London: HMSO, 1992).
Hanlon, Gregory, 'The decline of a provincial military aristocracy: Siena 1560-1740,' *Past and present* 155 (1997): 64-108.
Harley, Basil, "The society of arts' model ship trials 1758-1763,' *Transactions of the Newcomen Society* 63 (1991): 53-71.
Harley, C. Knick, 'Trade: discovery, mercantilism and technology,' R Floud and D. Johnson eds., *The Cambridge Economic History* (Cambridge: Cambridge University Press, 2nd edition., 1995), pp. 175-203.
Harley, J.B., *The new nature of maps: essays in the history of cartography*, edited by Paul Laxton (Baltimore: Johns Hopkins University Press, 2001).
Harris, John, 'Skills, coal and British industry in the eighteenth century,' *History* 61 (1976): 167-82.
Harris, John, *Industrial espionage and technology transfer: Britain and France in the eighteenth century* (Aldershot: Ashgate, 1998).
Harris, L. E., *Vermuyden and the Fens: a study of sir Cornelius Vermuyden and the great level* (London: Cleaver-Hume Press, 1953).
Harris, Steven J., 'Long-distance corporations, big sciences, and the geography of knowledge,' *Configurations* 6 (1998): 269-304.
Hartwell, R. M., *The causes of the Industrial Revolution in England* (London: Methuen, 1967).
Hashimoto T., 'Introducing a French technological system: the origins and early history of the Yokosuka dockyard,' *East Asian science, technology and medicine* 16 (1999): 53-72.

Hayward, J. F., *Virtuoso goldsmiths and the triumph of mannerism, 1540-1620* (London: Sotheby Park Bernet Publications, 1976).
Hayward, J.F., 'The mannerist goldsmith: Wenzel Jamnitzer,' *The connoisseur* 164 (1976): 148-154.
Headrick, Daniel, *When information came of age: technologies of knowledge in the age of reason and revolution, 1700-1850* (Oxford: Oxford University Press, 2000).
Helden, Albert van, 'Huygens and the astronomers,' Henk J.M. Bos et.al. eds., *Studies on Christiaan Huygens. Invited papers from the symposium on the life and work of Christiaan Huygens, Amsterdam, 22-25 August 1979*, (Lisse: Swets & Zeitlinger, 1980), pp. 147-165.
Heller, Henry, 'Primitive accumulation and technical innovation in the French Wars of Religion,' *History and technology* 16 (2000): 243-262.
Heller, Henry, *Labour, science and technology in France 1500-1620* (Cambridge: Cambridge University Press, 1996).
Hellman, C. Doris, 'The comet of 1577: its place in the history of astronomy' (Thesis, Columbia University, New York, 1944).
Heniger, J., *Hendrik Adrian van Reede tot Drakenstein and Hortus Malabaricus: a contribution to the study of Dutch colonial botany* (Rotterdam: Balkema, 1986).
Henninger-Voss, M., 'How the "new science" of cannons shook up the Aristotelian cosmos,' *Journal of the History of Ideas* 63 (2002): 371-397.
Henninger-Voss, M., 'Noble mechanics and working machines: Guidobaldo del Monte and the translation of knowledge,' *Isis* 91 (2000): 233-259.
Henson, Louise et al, eds., *Culture and science in the nineteenth-century media* (Aldershot: Ashgate, 2004).
Hesse, C., *Publishing and cultural politics in revolutionary Paris, 1789-1810* (Berkeley: University of California Press, 1991).
Hessenbruch, Arne, 'The spread of precision measurement in Scandinavia, 1660-1800,' Kostas Gavroglu, ed., *The Sciences in the European periphery during the Enlightenment* (Dordrecht: Kluwer, 1999): 179-224.
Hickel, Erika, 'Der Apothekerberuf als Keimzelle naturwissenschaftlicher Berufe in Deutschland,' *Medizinhistorisches Journal* 13 (1978): 259-276.
Hickel, Erika, *Arzneimittel-standardisierung im 19. Jahrhundert in den pharmakopöen Deutschlands, Frankreichs, Großbritanniens und der Vereinigten Staaten von Amerika* (Stuttgart: Wissenschaftliche Verlagsgesellschaft, 1973).
Hilaire-Pérez, Liliane and Catherine Verna, 'Dissemination of technical knowledge in the middle ages and the early modern era', *Technology and Culture* 47 (2006): 536-565.
Hilaire-Pérez, Liliane, *L'invention technique au siècle des lumières* (Paris: Albin Michel, 2000).
Hill, Christopher, *Reformation to Industrial Revolution: a social and economic history of Britain 1530-1780* (London: Weidenfeld & Nicolson, 1967).
Hill, Stephen, *The tragedy of technology* (London: Pluto Press, 1988).
Hills, Richard L., *James Watt: volume 2. The years of toil, 1775-1785* (Ashbourne: Landmark, 2005).
Hills, Richard, 'James Watt and paper and papermaking,' Peter Bower, ed., *The Exeter papers: proceedings of the British Association of Paper Historians, fifth annual conference* (2001): 65-73.
Hills, Richard, *Papermaking in Britain, 1488-1988: a short history* (London: Athlone Press, 1988).
Hilton, Boyd, *Corn, cash, commerce: the economic policies of the Tory governments 1815-1830* (Oxford: Oxford University Press, 1977).
Hilton, Boyd, *The age of atonement: the influence of Evangelicalism on social and economic thought, 1795-1865* (Oxford: Oxford University Press, 1988).
Hirschman A.O., *Development projects observed* (Washington DC: The Brookings Institution, 1967).

Hirschman, A.O. and Charles E. Lindblom, 'Economic development, research and development, policy making,' *Behavioural Science* 7-8 (1967-8): 211-22.

Hobsbawm, Eric, *Industry and empire: from 1750 to the present day*, revised and updated with Chris Wrigley (New York: New Press, 1999).

Hoeniger, F. David, 'How plants and animals were studied in the mid-sixteenth century,' John W. Shirley and F. David Hoeniger, eds., *Science and the arts in the Renaissance* (Washington DC, Folger Books, 1985), pp. 130-148.

Hollister-Short, Graham, 'Invisible technology, invisible numbers,' *Icon. Journal of the international committee for the history of technology* 1 (1995): 132-147.

Holmes, Frederic Lawrence, *Eighteenth-century chemistry as an investigative enterprise* (Berkeley: University of California Press, 1989).

Hoogewerff, G.J., *De twee reizen van Cosimo de' Medici, prins van Toscane, door de Nederlanden 1667-1669* (Amsterdam: Johannes Muller, 1919).

Hörmann, Johannes, 'Die königliche hofapotheke in Berlin (1598-1898),' *Hohenzollern-Jahrbuch* (1898): 208-226.

Howe, Anthony, 'Restoring free trade, 1776-1873,' Donald Winch and Patrick K. O'Brien eds., *The Political Economy of British Historical Experience*, pp. 193-213.

Hudson, Pat, 'Industrial organisation and structure', in R. Floud and P. Johnson, eds., *The Cambridge economic history of modern Britain. vol. 1: industrialisation, 1760-1860* (Cambridge: Cambridge University Press, 2004), pp. 28-56.

Hufbauer, Karl, *The formation of the German Chemical Community 1720-1795* (Berkeley: University of California Press, 1982).

Hughes, Edward, *Studies in administration and finance, 1558-1825* (Manchester: Manchester University Press, 1934).

Huhle-Kreutzer, Gabriele*, Die entwicklung arzneilicher produktionsstätten aus apothekenlaboratorien, dargestellt an ausgewählten beispielen* (Stuttgart: Deutscher Apotheker Verlag, 1989).

Hunt, Charles, *A history of the introduction of gas lighting* (London: Walter King, 1907).

Hunter, Dard, *Papermaking: the history and technique of an ancient craft* (New York: Dover Publications, 2nd ed., 1947; reprint, 1978).

Hunter, Michael, 'The cabinet institutionalized: the Royal Society's 'repository' and its background,' Oliver Impey and Arthur MacGregor, ed., *The origins of museums: the Cabinet of Curiosities in sixteenth- and seventeenth-century Europe* (London: House of Stratus, 2001), 159-168.

Hutchins, Edwin, *Cognition in the wild* (Cambridge, ma: MIT Press, 1995).

Hyman, A., *Charles Babbage: pioneer of the computer* (Princeton: Princeton University Press, 1982).

Iliffe, Robert, 'Mathematical characters: Flamsteed and Christ's Hospital Royal Mathematical School,' Frances Willmoth, ed., *Flamsteed's stars* (Woodbridge: Boydell and Brewer, 1997), pp. 115-144.

Inkori, Joseph E., *Africans and the Industrial Revolution in England: a study in international trade and economic development* (Cambridge: Cambridge University Press, 2002).

Inkster Ian, 'Technological and industrial change: a comparative essay,' Roy Porter ed., *Eighteenth century science,* Vol. 4 of *The Cambridge history of science* (Cambridge: Cambridge University Press, 2003), pp. 845-881.

Inkster, Ian, 'Potentially global: 'useful and reliable knowledge' and material progress in Europe, 1474-1914,' *International history review* 28 (2006): 237-286.

Inkster, Ian, 'Discoveries, inventions and industrial revolutions: on the varied contributions of technologies and institutions from an international historical perspective,' *History of technology* 18 (1996): 39-58.

Inkster, Ian, *The Japanese industrial economy. Late development and cultural causation* (London: Routledge, 2001).

Innes Smith, R.W., *English-speaking students of medicine at the University of Leyden* (Edinburgh: Oliver and Boyde, 1932).

Jackson, Myles, 'Natural and artificial budgets: accounting for Goethe's economy of nature,' Michael Power, ed., *Accounting and science: natural inquiry and commercial reason* (Cambridge: Cambridge University Press, 1994): 57-80.

Jacob, James, *Robert Boyle and the English Revolution* (New York: Burt Franklin, 1977).

Jacob, Margaret C. and Larry Stewart, *Practical matter. Newton's science in the service of industry and empire 1687-1851* (Cambridge, ma: Harvard University Press, 2004).

Jacob, Margaret C., *Scientific culture and the making of the industrial West* (Oxford: Oxford University Press, 1997).

Jarvis, Rupert, 'The paper-makers and the excise in the eighteenth century,' *The Library*, 5th ser., 14 (1959): 100-116.

Jasanoff, Sheila, *The co-production of science and social order* (London: Routledge, 2004).

Johns, A.W., 'An account of the society for the improvement of naval architecture,' *Transactions of the institution of naval architects* 52 (1910): 28-40.

Johns, Adrian, 'Grub Street pirates and the plausibility of print,' at http://csb.princeton.edu/index.php?app=download&id=9.

Johns, Adrian, 'The ambivalence of authorship in early modern natural philosophy,' M. Biagioli and P. Galison, eds., *Scientific authorship: credit and intellectual property in science* (New York: Routledge, 2003), pp. 67-90.

Johns, Adrian, *The nature of the book: print and knowledge in the making* (Chicago: University of Chicago Press, 1998).

Johnston, Stephen, 'Making mathematical practice: gentlemen, practitioners and artisans in Elizabethan England' (PhD thesis, Cambridge University 1994).

Johnstone, Paul H., 'The rural Socrates,' *Journal of the history of ideas* 5 (1944): 151-175.

Jong, Erik de, Clemens Steenbergen and Peter de Zeeuw, 'De Beemster. Een arena van natuur, kunst en techniek,' *Nederland als kunstwerk; vijf eeuwen bouwen door ingenieurs*, ed., Toon Lauwen (Rotterdam: Nai Uitgevers, 1995): 154-167.

Jong, Erik de, *Natuur en kunst; Nederlandse tuin- en landschapsarchitectuur 1650-1740* (Bussum, Wageningen: Uitgeverij Thoth, 1995).

Joyce, Patrick, *The rule of freedom* (London: Verso, 2003).

Karmon, David, 'Restoring the ancient water supply system in Renaissance Rome: the Popes, the civic administration, and the Acqua Vergine,' *The waters of Rome*, 2005, 3: unpaginated, http://www.iath.virginia.edu/waters/karmon.html.

Kearney, H. F., 'The political background to English mercantilism, 1695-1700,' *Economic history review* 11 (1959): 484-496.

Keller, Charles and Janet Dixon Keller, 'Thinking and acting with iron,' Seth Chaiklin and Jean Lave, eds., *Understanding practice: perspectives on activity and context* (Cambridge: Cambridge University Press, 1993), pp. 125-143.

Kemp, Martin, *The science of art* (New Haven and London, 1990).

Kepler, Johannes, *Optics. Paralipomena to Witelo & optical part of astronomy*, transl. William H. Donahue (Santa Fe: Green Lion Press, 2000).

Kidd, Colin, 'Hybridity,' *London review of books*, 26 (2 September 2004): 14-15.

Kinleberger, C. P., 'The rise of free trade in western Europe, 1820-1875,' *Journal of economic history* 35 (1975): 20-55.

Klaus Pechstein, 'Zeichnungen von Wenzel Jamnitzer,' *Anzeiger des Germanischen nationalmuseums* (1970): 81-95.

Kleijn, Gerda de, *The water supply of ancient Rome; city area, water and population* (Amsterdam: Gieben, 2001).

Klein, Ursula and Wolfgang Lefèvre, *Materials in eighteenth-century science: a historical ontology* (Cambridge, ma: MIT Press, 2007).

Klein, Ursula, 'Apothecary-chemists in eighteenth-century Germany,' Lawrence M. Principe, ed., *New narratives in eighteenth-century chemistry* (Dordrecht: Springer, forthcoming).

Klein, Ursula, 'Experiments at the Intersection of experimental history, technological inquiry, and conceptually driven analysis,' *Perspectives on science* 13 (2005): 1-48.

Klein, Ursula, 'Technoscience avant la lettre,' *Perspectives on science* 13 (2005): 226-266.

Knorr-Cetina, Karin, *Epistemic cultures* (Cambridge, ma: Harvard University Press, 1999).

Koerner, Lisbet, *Linnaeus: nature and nation* (Cambridge, ma.: Harvard University Press, 1999).

Köhnke, Otto, 'Gesammtregister über die in den Schriften der Akademie von 1700-1899 erschienenen wissenschaftlichen Abhandlungen und Festreden,' in Adolf Harnack, ed., *Geschichte der Königlich Preussischen Akademie der Wissenschaften zu Berlin* (Berlin: Reichsdruckerei, 1900, 3 vols.), vol. 3.

Kölker, A.J., G.H. Keunen, and D. de Vries, eds., *De Beemster* (Alphen aan de Rijn: Canaletto, 1985).

Korthals Altes, J., *Polderland in Italië; de werkzaamheden der Nederlandsche bedijkers in vroeger eeuwen en het Italiaansche polderland voorheen en thans* (Den Haag: Stockum, 1928).

Korthals-Altes, J., *Sir Cornelius Vermuyden: the lifework of a great Anglo-Dutchman in land-reclamation and drainage* (London: Williams & Norgate, and The Hague: W. P. Stockum & Son, 1925).

Koyré, Alexandre *From the closed world to the infinite universe* (Oxford: Oxford University Press, 1957).

Koyré, Alexandre, 'Galileo and Plato,' *Journal of the history of ideas* 4 (1943): 400-428.

Koyré, Alexandre, *Études galiléennes* (Paris: Hermann, 1966 (1939)).

Krüger, Mechthild, *Zur geschichte der elixiere, essenzen und tinkturen* (Braunschweig: Technische Hochschule, 1968).

Kubler, G.A., *A new history of stereotyping* (New York: Little & Ives, 1941).

Kubler, G.A., *Historical treatises, abstracts, and papers on stereotyping* (New York: Brooklyn Eagle, 1936).

Kubler, G.A., *The era of Charles Mahon, third earl of Stanhope, stereotyper, 1750-1825* (New York: G.A. Kubler, 1938).

Kuo, Ting-yee and Kwang-ching Liu, 'Self-strengthening: the pursuit of western technology,' John K. Fairbank, ed., *The Cambridge History of China* 10, part 1 (Cambridge: Cambridge University Press, 1978): 491-542.

Kusukawa, Sachiko, *From counterfeit to canon: Picturing the human body, especially by Andreas Vesalius*, Preprint 281 (Berlin: Max-Planck-Institut für Wissenschaftsgeschichte, 2004).

Lackner M. and N. Vittinghoff, eds., *Mapping meanings: the field of new learning in late Qing China* (Leiden: Brill Academic Publishers, 2004).

Laird, W.R., *The unfinished mechanics of Giuseppe Moletti.* (London: University of Toronto Press, 2000).

Lambert, Audrey M., *The making of the Dutch landscape, a historical geography of the Netherlands* (London, New York: Seminar Press, 1971).

Lanciani, Rodolfo, *Le acque e gli Acquedotti di Roma antica* (Rome, 1881).

Lanciani, Rodolfo, *The golden days of the Renaissance in Rome* (Boston and New York: Houghton Mifflin and Company, 1906).
Landes, David, *The unbound Prometheus: technological change and industrial development in western Europe from 1750 to the present* (Cambridge: Cambridge University Press, 1969).
Lane, Frederic Chapin, *Venetian ships and shipbuilders of the Renaissance* (Baltimore: Johns Hopkins University Press, 1934).
Langford, John Alfred, *A century of Birmingham life*, 2 vols. (Birmingham: W. G. Moore, 1870).
Langins, Janis, *Conserving the Enlightenment: French military engineering from Vauban to the revolution* (Cambridge, ma: MIT Press, 2004).
Latour, Bruno and Michel Callon, 'Don't throw the baby out with the Bath school,' Andrew Pickering, ed., *Science as Practice and Culture* (Chicago: University of Chicago Press, 1992), pp. 343-368.
Latour, Bruno, 'Visualization and cognition: Thinking with eyes and hands,' *Knowledge and society: studies in the sociology of culture past and present* 6 (1986): 1-40.
Latour, Bruno, and Steve Woolgar, *Laboratory life: the [social] construction of scientific facts* (Princeton: Princeton University Press, 1979).
Latour, Bruno, *Science in action: how to follow scientists and engineers through society* (Cambridge, ma: Harvard University Press, 1987).
Laudan, Rachel, 'Cognitive change in technology and science,' Rachel Laudan, ed., *The nature of technological knowledge. Are models of scientific change relevant?* (Dordrecht, Boston, Lancaster: D. Reidel Publishing Co., 1984), pp. 83-104.
Laudan, Rachel, 'Histories of the sciences and their uses: a review to 1913,' *History of science* 31 (1993): 1-34.
Laurie Nussdorfer, *Civic politics in the Rome of Urban VIII* (Princeton, NJ: Princeton University Press, 1992).
Lauterbach, Christiane, *Gärten der musen und grazien, mensch und natur im Niederländischen Humanistengarten 1522-1655* (Munchen, Berlin: Deutscher Kunstverlag, 2004).
Lauterbach, Irene, *Christian Wilhelm Trommsdorff (1811–1884): Zu leben und werk eines pharmazeutischen unternehmers* (Stuttgart: Wissenshaftliche Verlagsgesellschaft, 2000).
Lauwen, Toon, ed., *Nederland als kunstwerk; vijf eeuwen bouwen door ingenieurs* (Rotterdam: Nai Uitgevers, 1995).
Lave, Jean and Etienne Wenger, *Situated learning: legitimate peripheral participation* (Cambridge: Cambridge University Press, 1991).
Lave, Jean, 'Cognitive consequences of traditional apprenticeship training in West Africa,' *Anthropology and education quarterly* 8 (1977): 170-80.
Lavery, Brian and Simon, Stephens, *Ship models: their purpose and development from 1650 to the present* (London: Zwemmer, 1995).
Lebra, Takie S., *The Japanese self in cultural logic* (Honolulu: University of Hawaii Press, 2004).
Lefebvre, E., and J.G. De Bruijn, eds., *Martinus van Marum. Life and works*, Vol. 4, G.L' E. Turner and T.H. Levere, *Van Marum's scientific instruments in Teyler's Museum* (Leiden: Noorhhoff, 1973).
Lehman, Christine, *Gabriel-François Venel, sa place dans la chimie française du XVIII^{e} siècle* (Thèse, Université Paris X, 2006).
Lehmann, Herbert, *Das collegium medico-chirurgicum in Berlin als lehrstätte der botanik und der pharmazie* (Berlin: Triltsch & Huther, 1936).
Lenman, Bruce P., 'Jacobean goldsmith-jewellers as credit-creators: the cases of James Mossman, James Cockie and George Heriot,' *The Scottish historical review* 74 (1995): 159-177.

Lente, Dick van, 'Innovation in paper making: The Netherlands, 1750-1850,' *History and technology* 14 (1998): 201-224.
Levesque, Catherine, 'Landscape, politics and the prosperous peace,' *Nederlands Kunsthistorisch Jaarboek* 48 (1997): 222-257.
Licoppe, Christian, *La formation de la pratique scientifique: Le discours de l'expérience en France et en Angleterre, 1630-1820* (Paris: Éditions La Découverte, 1996).
Lindgren, M., *Glory and failure: the difference engines of Johann Müller, Charles Babbage and Georg and Edvard Scheutz* (Cambridge, MA: MIT Press, 1990).
Lindley, Keith, *Fenland riots and the English revolution* (London: Heinemann Educational Books, 1982).
Lindqvist, Svante, 'Labs in the woods: the quantification of technology during the late Enlightenment,' Tore Frangsmyr, J.L.Heilbron and Robin E. Rider, eds., *The quantifying spirit in the eighteenth century* (Berkeley: University of California Press, 1990), pp. 291-314.
Linebaugh, Peter and Marcus Rediker, *The Many-Headed Hydra: sailors, slaves, commoners and the hidden history of the revolutionary Atlantic* (Boston: Beacon Press, 2000).
Linebaugh, Peter, *The London hanged: crime and civil society in the eighteenth century* (London: Penguin, 1993).
Lipson, E., *The economic history of England*, 3 Vols, (London: Black, 1943).
Liu, Chun-yu (Jerry), *Comparative studies of European and Chinese cultural identity – a conceptual and historical approach* (PhD dissertation, Faculty of Arts and Humanities, The Nottingham Trent University, United Kingdom, 2002).
Liu, Jerry C.Y., 'Cultural logics for the regime of useful knowledge during the Ming and early Qing China c. 1400-1700,' The 9th Global Economic History Network Conference, LSE and Wenzao Ursuline College of Languages, 9-11 May 2006, Kaohsiung, Taiwan.
Livingstone, David, *Putting science in its place: geographies of scientific knowledge* (Chicago: Chicago University Press, 2003).
Lohne, Johannes, 'Kepler und Harriot. Ihre Wege zum Brechungsgesetz,' Fritz Kraft et.al., eds., *Internationales Kepler-Symposium, Weil der Stadt (8. Bis 11. August 1971): Referate und Diskussionen* (Hildesheim: Gerstenberg, 1973): 187-213.
Lohne, Johannes, 'Zur geschichte des Brechungsgesetzes,' *Sudhoffs Archiv* 47 (1963): 152-172.
Long, Pamela, 'Engineering, power, and knowledge in early counter-reformation Rome, c. 1557-1570,' an unpublished paper circulated by the Davis Center, Princeton University, December 2004.
Long, Pamela, *Openness, secrecy, authorship: technical arts and the culture of knowledge from Antiquity to the Renaissance* (Baltimore: Johns Hopkins University Press, 2001).
Longino, Helen, *Science as social knowledge* (Princeton: Princeton University Press, 1990).
Lorenz, Hermann, 'Die ratsapotheke zu Quedlinburg,' transcript of the *Quedlinburger Kreisblatt*, 1928, Nr. 178-181, Universitätsbibliothek Freie Universität Berlin.
Lorne Campbell, Susan Foister, and Ashok Roy, 'The materials and technique of five paintings by Rogier van der Weyden and his workshop,' *National Gallery technical bulletin*, 18 (1997): 68-86.
Löw, Carl, *Heinrich Emanuel Merck* (Darmstadt: E. Roether, 1951).
Lunn, Kenneth and Ann, Day, eds., *History of work and labour relations in the Royal Dockyards* (London: Mansell, 1999).
Lynn, Michael R., 'Divining the Enlightenment: public opinion and popular science in old regime France,' *Isis* 22 (2001): 34-54.

Maarten Prak, ed., *Early modern capitalism: economic and social change in Europe 1400-1800* (London: Routledge, 2001).
MacLeod, Christine, 'The European origins of British technological predominance,' in L.P. de la Escosura, ed., *Exceptionalism and industrialism: Britain and its European rivals 1688-1815* (Cambridge: Cambridge University Press, 2004): 111-26.
MacLeod, Christine, *Inventing the Industrial Revolution: the English patent system 1688-1800* (Cambridge: Cambridge University Press, 1988).
Maffioli, C.S., 'Italian hydraulics and experimental physics in eighteenth-century Holland,' C.S.Maffioli and L.C.Palm, eds., *Italian scientists in the Low Countries in the XVIIth and XVIIIth centuries* (Amsterdam: Rodopi, 1989), pp. 243-75.
Maffioli, C.S., *Out of Galileo: The science of waters 1628-1718* (Rotterdam: Erasmus, 1994).
Mah, Harold, 'Phantasies of the public sphere: rethinking the Habermas of historians,' *Journal of modern history* 72 (2000): 153-182.
Maistre, André, *Le Canal des Deux-Mers* (Paris: Privat, 1998).
Malavialle, M. L., 'Une Excursion dans la Montagne Noire, Part I,' *Société Languedocienne de Géographie Bulletin* 14 (1891): 280-284.
Manning, Brian, *The English people and the English Revolution* (Harmondsworth: Penguin, 1978).
Marchetti, Raffaele, *Sulle acque di Roma antiche e moderne* (Rome, 1886).
Markus, Thomas, *Buildings and power: freedom and control in the origin of modern building types* (London: Routledge, 1993).
Mathias, Peter and John A. Davis, eds., *The first industrial revolutions* (Oxford: Blackwell, 1989).
Mathias, Peter, *The transformation of England: essays in the economic and social history of England in the Eighteenth Century* (New York: Columbia University Press, 1979) (London: Methuen, 1979).
Maxted, Ian, *The London book trades 1775-1800* (London: Dawson, 1977).
Mayer, Anna-K., 'Setting up a discipline, ii: British history of science and 'the end of ideology,'' *Studies in history and philosophy of science* 35A (2004): 41-72.
Mayer, Anna-K.,'Setting up a discipline: conflicting agenda of the Cambridge history of science committee, 1936-1950,' *Studies in history and philosophy of science* 31A (2000): 665-689.
Mayhew, Robert, 'Mapping science's imagined community: geography as a Republic of Letters, 1600-1800,' *British journal of the history of science* 38 (2005): 73-92.
McGaw, Judith, *Most wonderful machine: mechanization and social change in berkshire paper making, 1801-1885* (Princeton: Princeton University Press, 1987).
McGee, David, 'From craftsmanship to draftsmanship: naval architecture and the three traditions of early modern design,' *Technology and culture* 40 (1999): 210-36.
McGowen, Randall, 'From pillory to gallows: the punishment of forgery in the age of the financial revolution,' *Past and present* 165 (1999): 107-140.
McKendrick, Neil, 'Josiah Wedgwood and factory discipline,' *Historical journal* 4 (1961): 30-55.
McKitterick, D.J., *Print, manuscript, and the search for order* (Cambridge: Cambridge University Press, 2003).
McMullen, E.T., 'The origins of Descartes mechanical philosophy,' *Georgia journal of science* 60 (2002): 127-143.
Meinecke, Ulla, 'Apothekenbindung und Freiverkäuflichkeit von Arzneimitteln: Darstellung der historischen Entwicklung bis zur Kaiserlichen Verordnung von 1901 unter besonderer Berücksichtigung des Kurfürstentums Brandenburg und des Königreichs Preußen' (PhD thesis, University of Marburg, 1971).
Merton, Robert K., *Science, technology and society in seventeenth-century England* (New York: Harper and Row, 1970).

Miller, David Philip, "'Puffing Jamie': the commercial and ideological importance of being a 'philosopher' in the case of the reputation of James Watt (1736-1819),' *History of science* 38 (2000): 1-24.
Miller, David Phillip, 'The revival of the physical sciences in Britain 1815-1840,' *Osiris* 2 (1986): 107-34.
Misa, Thomas J., *Leonardo to the Internet: technology and culture from the Renaissance to the present* (Baltimore: Johns Hopkins University Press, 2004).
Mokyr, Joel, *Lever of Riches* (New York: Oxford University Press, 1990).
Mokyr, Joel, 'The intellectual origins of modern economic growth,' *Journal of Economic History* 65 (2005): 285-351.
Mokyr, Joel, ed., *The British Industrial Revolution. An economic perspective* (Boulder, Colorado: Westview Press, 1993).
Mokyr, Joel, *Industrialization in the Low Countries, 1795-1850* (New Haven: Yale University Press, 1976).
Mokyr, Joel, *The gifts of Athena: historical origins of the knowledge economy* (Princeton: Princeton University Press, 2002).
Molhuysen, P.C., *Bronnen tot de geschiedenis der Leidsche Universiteit, 1574-1610* (Den Haag: Martinus Nijhoff, 1913).
Moore, J. R., *Daniel Defoe: citizen of the modern world* (Chicago: Chicago University Press, 1958).
Morgan, Edmund, *The genuine article: a historian looks at early America* (New York: Norton, 2004).
Mornet, Daniel, *Les origines intellectuelles de la révolution française* (Paris: Colin, 1933).
Morriss, Roger, 'Labour relations in the dockyards 1801-5,' *Mariner's Mirror* 62 (1976): 337-46.
Morriss, Roger, *The Royal Dockyards during the Revolutionary and Napoleonic wars* (Leicester: Leicester University Press, 1983).
Morriss, Roger,'Samuel Bentham and the management of the Royal Dockyards,' *Bulletin of the Institute of Historical Research* 54 (1981): 226-40.
Morton, Alan Q., and Jane A. Wess, *Public and private science: the King George III collection* (Oxford: Oxford University Press, 1993).
Morus, Iwan Rhys, *Frankenstein's children: electricity, exhibition and experiment in early nineteenth century London* (Princeton: Princeton University Press, 1998).
Mui H. and L.H. Mui, *Shops and shopkeepers in eighteenth-century England* (London: Routledge, 1989).
Muirhead, J.P., *The origin and progress of the mechanical inventions of James Watt,* volume 2 (London: J. Murray, 1854).
Muirhead, James Patrick, *The life of James Watt* (New York, 1859).
Mukerji, Chandra 'Entrepreneurialism, land management and cartography during the age of Louis XIV,' Paula Findlen and Pamela H. Smith, eds., *Merchants and marvels* (New York: Routledge, 2002), pp. 248-276.
Mukerji, Chandra *A fragile power: science and the state* (Princeton: Princeton University Press, 1990).
Mukerji, Chandra *Territorial ambitions and the gardens of Versailles* (Cambridge: Cambridge University Press, 1997).
Mukerji, Chandra, 'Bourgeois culture and French gardening in the sixteenth and seventeenth centuries,' M. Conan, ed., *Bourgeois and aristocratic cultural encounter in garden art, 1550-1850* (Washington: Dumbarton Oaks Research Library and Collection, 2002), pp. 173-187.
Mukerji, Chandra, 'Storehouses to stoves: built environments and the early Dutch plant trade,' an unpublished paper presented at the symposium 'Dutch culture in the Golden Age,' University of Pennsylvania, Philadelphia, 1999.

Mukerji, Chandra, 'Women engineers and the culture of the Pyrenees,' Pamela H. Smith and Benjamin Schmidt, eds., *Knowledge and its making in Europe, 1500-1800* (University of Chicago Press, forthcoming).

Muller E. and K. Zandvliet, *Admissies als landmeter in Nederland voor 1811. Bronnen voor de geschiedenis van de landmeetkunde en haar toepassing in administratie, architectuur, kartografie en vesting- en waterbouwkunde* (Alphen aan den Rijn: Cannaleto, 1987).

Muntz, Eugene, *Les arts à la cour des Papes Pendant le XV^e^ et le XVI^e^ siècle, recueil de documents inédits*, Duexième Partie, Paul II (1464-1471) (Paris: 1879).

Musson A.E. and Eric Robinson, *Science and technology in the Industrial Revolution* (Manchester: Manchester University Press, 1969).

Musson, A.E., 'James Nasmyth and the early growth of mechanical engineering,' *Economic history review* 10 (1957): 121-127.

Naylor, R.H., 'Galileo's theory of projectile motion,' *Isis* 71 (1980): 550-570.

Needham, Joseph, et al, *Science and civilization in China* (Cambridge: Cambridge University Press, 1954-2004).

Nieto-Galan, Agustí, ed., *Colouring textiles: a history of natural dyestuffs in industrial Europe* (Dordrecht: Kluwer, 2001).

Noble, David, 'Social choice in machine design: the case of automatically controlled machine tools,' Donald MacKenzie and Judy Wajcman, eds., *The Social Shaping of Technology* (New York: MacGraw Hill, 1999), pp. 161-176.

Norris, J. M., 'Samuel Garbett and the early development of industrial lobbying in Great Britain,' *Economic history review* 10 (1958): 450-460.

Nowotny, Helga, Peter Scott and Michael Gibbons, *Rethinking science: knowledge and the public in an age of uncertainty* (Cambridge: Polity Press, 2001).

Nussbaum, Martha *Upheavals of thought* (Cambridge: Cambridge University Press, 2001).

O'Brien, P. K., T. Griffiths and P. Hunt, 'Political components of the Industrial Revolution: Parliament and the English textile industry, 1660-1774,' *Economic history review* 44 (1991): 395-423.

O'Connell, Joseph, 'Metrology: the creation of universality by the circulation of particulars,' *Social studies of science* 23 (1993): 129-73.

O'Brien, P. K., 'The political economy of British taxation, 1660-1815,' *Economic history review* 41 (1988): 1-32.

Ogborn, Miles, *Spaces of modernity: London's geographies 1680-1780* (New York: Guilford Press, 1998).

Olmsted, John W., 'Jean Picard's 'membership' in the Académie Royale des Sciences, 1666-1667: the problem and its implications,' Guy Picolet, ed., *Jean Picard et les débuts de l'astronomie de précision au XVII^e^ siècle* (Paris: Éditions du Centre National de la Recherche Scientifique, 1987): 85-116.

Ormrod, David, *The rise of commercial empires: England and the Netherlands in the age of mercantilism, 1650-1770* (Cambridge: Cambridge University Press, 2003).

Otterspeer, Willem, *Groepsportret met Dame I; het bolwerk van de vrijheid; de Leidse universiteit 1575-1672* (Amsterdam: Bert Bakker, 2000).

Oxford Dictionary of National Biography (Oxford: Oxford University Press, 2004).

Panofsky, Erwin, *The life and art of Albrecht Dürer* (Princeton: Princeton University Press, 1955).

Parker, Geoffrey, *The military revolution: military innovation and the rise of the West, 1500-1800* (Cambridge: Cambridge University Press, 1988).

Parthasarathi, Prasannan, 'Rethinking wages and competitiveness in the eighteenth century: Britain and south India,' *Past and present* 158 (1998): 79-109.

Pecchiai, Pio, *Acquedotti e Fontane di Roma nel cinquecento* (Rome: Staderini, 1944).
Pérez-Ramos, Antonio, *Francis Bacon's idea of science and the maker's knowledge tradition* (Oxford: Clarendon Press, 1988).
Pestre, Dominique, 'Regimes of knowledge production in society: towards a more political and social reading,' *Minerva* 41 (2003): 245-261.
Pestre, Dominique, 'Science des philosophes, science des historiens,' *Débats* 102 (1998): 99-106.
Pestre, Dominique, 'The production of knowledge between academies and markets,' *Science, technology and society* 5 (2000): 169-181.
Phillimore, R.H., *Historical records of the survey of India*, 4 vols. (Dehra Dun: Surveyor General of India, 1945).
Picon, Antoine, 'L'idée de nature chez les ingénieurs des ponts et chaussées,' Andrée Corvol, ed., *La Nature en Révolution 1750-1800* (Paris: L'Harmattan, 1993), pp. 117-125.
Picon, Antoine, 'Towards a history of technological thought,' Robert Fox, ed., *Technological Change* (Amsterdam: Harwood Academic, 1996), pp. 37-49.
Pitte, Jean-Robert, *Histoire du Paysage Français; Le Profane: du XVI^e siècle à nos jours* (Paris: Talandier, 1983).
Ploeg, Willem, *Constantijn Huygens en de natuurwetenschappen* (Rotterdam: Nijgh & van Ditmar, 1934).
Pols, Kees van der and Jan Verbruggen, *Stoombemaling in Nederland/Steam drainage in the Netherlands, 1770-1870* (Delft: Delft University Press, 1996).
Pomeranz, K., *The Great Divergence* (Princeton: Princeton University Press, 2000).
Porter, Roy and Mikulas Teich, eds., *Revolution in history* (Cambridge: Cambridge University Press, 1986).
Porter, Roy, *Enlightenment: Britain and the creation of the modern world* (London: Penguin Books, 2001).
Porter, Theodore M., *Trust in numbers: the pursuit of objectivity in science and public life* (Princeton: Princeton University Press, 1995).
Pouls, H.C., *De landmeter Jan Pietersz Dou en de Hollandse Cirkel* (Delft: Nederlandse Commissie voor Geodesie, 2004).
Power, Michael, 'From the science of accounts to the financial accountability of science,' *Science in context* 7 (1994): 355-87.
Power, Michael, *The audit society: rituals of verification* (Oxford: Oxford University Press, 1997).
Presenti, Allegra, 'Communicating design: drawings for the patron in Italy 1400-1600,' paper given at the V&A Seminar 3 February 2004.
Prest, John, *The Garden of Eden – the botanic garden and the re-creation of paradise* (New Haven, London: Yale University Press, 1988).
Pritchard, James, 'From shipwright to naval constructor: the professionalization of 18th century French naval shipbuilders,' *Technology and culture* 28 (1987): 1-25.
Proctor, Robert N., *Value-free science? Purity and power in modern knowledge* (Cambridge, MA: Harvard University Press, 1991).
Prothero, Iorwerth, *Artisans and politics in early nineteenth century London* (Folkestone: Dawson, 1979).
Pullan, Brian, 'The occupations and investments of the Venetian nobility in the middle and late sixteenth century,' J.R. Hale, ed., *Renaissance Venice* (Totowa, NJ: Rowman and Littlefield, 1973).
Raj, Kapil, 'Circulation and the emergence of modern mapping: Great Britain and early colonial India, 1764-1820,' Claude Markovits, Jacques Pouchepadass & Sanjay Subrahmanyam,

eds., *Society and circulation: mobile people and itinerant cultures in South Asia 1750-1950* (New Delhi: Permanent Black, 2002): 23-54.
Rediker, Marcus, *Between the devil and the deep blue sea: merchant seamen, pirates and the Anglo-American maritime world 1700-1750* (Cambridge: Cambridge University Press, 1987).
Redondi, Pietro, 'Along the water: the genius and the theory. D'Alembert, Condorcet and Bossut and the Picardy canal controversy,' *History and technology* 2 (1985): 77-110.
Redondi, Pietro, *Galileo heretic* (Princeton: Princeton University Press, 1987).
Reeves, Eileen, *Painting the heavens* (Princeton: Princeton University Press, 1997).
Reh, Wouter and Clemens Steenbergen, eds., *Zee van land. De droogmakerij als architectonisch experiment* (Delft: Technische Universiteit, 1999).
Reith, Reinhold, 'Technische innovationen im handwerk der Frühen Neuzeit,' Karl Heinrich Kaufbold and Wilfried Reininghaus, eds., *Stadt und handwerk in Mittelalter und Früher Neuzeit* (Köln: Böhlau, 2000), pp. 21–60.
Renn, Jürgen and Matteo Valleriani, 'Galileo and the challenge of the Arsenal,' *Nuncius* 16 (2001): 481-503.
Renn, Jurgen, Peter Damerow and Simone Rieger, 'Hunting the white elephant: when and how did Galileo discover the law of fall?,' *Science in context* 13 (2000): 299-419.
Reynolds, Terry, *Stronger than a hundred men: a history of the vertical water wheel* (Baltimore: Johns Hopkins University Press, 1983).
Ribbe, Wolfgang, ed., *Geschichte Berlins* (Berlin: BWV–Berliner Wissenschafts-Verlag, 2002, 2 vols.).
Ribe, Neil M., 'Cartesian optics and the mastery of nature,' *Isis* 88 (1997): 42-61.
Rinne, Katherine, 'Fluid precision: the Acqua Vergine Fountains of Giacomo Della Porta,' Jan Birksted, ed., *Landscapes of memory and experience*, (London: Routledge, 2000).
Riskin, Jessica, 'Poor Richard's leyden jar: electricity and economy in Franklinist France,' *Historical studies in the physical and biological sciences* 28 (1998): 301-336.
Rivolta, Adolfo. *Catalogo dei Codici Pinelliani dell'Ambrosiana* (Milan: Tipografia Arcivescovile S. Giuseppe, 1933).
Roberts, Lissa 'An Arcadian apparatus: the introduction of the steam engine into the Dutch landscape,' *Technology and culture* 45 (2004): 251-276.
Roberts, Lissa, 'Devices without borders: what an eighteenth-century display of steam engines can teach us about 'public' and 'popular' science,' *Science and education* 16 (2007): 561-572.
Roberts, Lissa, 'Going Dutch: situating science in the Dutch Enlightenment,' William Clark, Jan Golinski and Simon Schaffer, eds., *The sciences in enlightened Europe* (Chicago: University of Chicago Press, 1999), pp. 350-388.
Roberts, Lissa, 'Policy and practice: defining the 'science' in 'science policy',' *Minerva* (under review).
Roberts, Lissa, 'Science becomes electric: Dutch interactions with the electrical machine during the eighteenth century,' *Isis* 90 (1999): 680-714.
Roberts, Lissa, 'Setting the table: the disciplinary development of eighteenth-century chemistry,' Peter Dear, ed., *The literary structure of scientific argument* (1991): 99-132.
Roberts, Lissa, 'The death of the sensuous chemist,' *Studies in the history and philosophy of science* 26 (1995): 503-29.
Robinson, Eric and Douglas McKie, eds., *Partners in science: letters of James Watt & Joseph Black* (London: Constable, 1970).
Rochas d'Aiglun, Albert de *Vauban, sa famille et ses écrits ses oisivetes et sa correspondance. Analyse et extraits*. Tome I. (Genève: Slatkin reprints, 1972).

Rodger, N.A.M., *The insatiable Earl: a life of John Montagu, fourth earl of Sandwich* (London: Harper Collins, 1993).
Rodger, N.A.M., *The command of the ocean: a naval history of Britain 1649-1815* (London: Penguin, 2005).
Rodger, N.A.M., *The wooden world: an anatomy of the Georgian navy* (London: Fontana, 1988).
Roever, J.G. de, *Jan Adriaenszoon Leeghwater, het leven en werk van een zeventiende-eeuws waterbouwkundige* (Amsterdam: Wed., J. Ahrend, 1944).
Rolt, L.T.C., *From sea to sea* (Ohio University Press, 1973).
Rooseboom, Maria, *Bijdrage tot de geschiedenis der instrumentmakerskunst in de noordelijke Nederlanden tot omstreeks 1840* (Leiden: Rijksmuseum voor de Geschiedenis der Natuurwetenschappen, 1950).
Rose, Paul Lawrence, 'A Venetian patron and mathematician of the sixteenth century: Francesco Barozzi (1537-1604),' *Studi Veneziani* 1(1977): 119-178.
Rose, Paul Lawrence, 'Jacomo Contarini (1536-1595), a Venetian patron and collector of mathematical instruments,' *Physis* 18 (1976): 117-130.
Rose, Paul Lawrence, 'The origins of the proportional compass from Mordente to Galileo,' *Physis* 10 (1968): 53-67.
Rosenband, Leonard N., 'Never Just Business: David Landes, *The Unbound Prometheus*,' *Technology and culture*, 46 (2005): 168-176.
Rosenband, Leonard N., 'The competitive cosmopolitanism of an old regime craft,' *French historical studies* 23 (2000): 455-76.
Rosenband, Leonard, 'Comparing combination acts: French and English papermaking in the age of revolution,' *Social history* 29 (2004): 165-185.
Rosenband, Leonard, 'Jean-Baptiste Réveillon: a man on the make in old regime France,' *French historical studies* 20 (1997): 481-510.
Rosenband, Leonard, 'Nicolas Desmarest and the transfer of technology in old regime France,' Karen Merrill, ed., *The modern worlds of business and industry: cultures, technology, labour* (Turnhout: Brepols, 1998).
Rosental, Claude, 'Une sociologie des formes de démonstration,' *Mémoire pour l'habilitation à diriger des recherches*. (2004).
Rosental, Claude, *La Trame de l'évidence: sociologie de la démonstration en logique* (Paris; Presses Universitaires de France, 2003).
Rossi, Paolo, *Francis Bacon: from magic to science*, trans. Sacha Rabinovitch (Chicago: University of Chicago Press, 1968).
Rossi, Paolo, *Philosophy, technology and the arts in the early modern era* (New York: Harper and Row, 1970).
Rostow, Walter W., ed., *The economics of take-off* (London: Macmillan Press, 1963).
Rostow, Walter W., *The beginnings of modern economic growth* (Oxford: Oxford University Press, 1953, 2nd edition, 1960).
Rostow, Walter W., *The stages of economic growth: a non-communist manifesto* (Cambridge: Cambridge University Press, 1960).
Rule, John, *The labouring classes in early industrial England 1750-1850* (London: Longman, 1986).
Rummonds, R.-G., ed., *Nineteenth-century printing practices and the iron handpress* (2 vols. New Castle, DE: Oak Knoll Press/British Library, 2004).
Rycroft R.W. and J.S. Szyliowics, 'The technological dimensions of decision making; the case of the Aswan High Dam,' *World politics* 33 (1980): 36-51.

Salomon, Gavriel, ed., *Distributed cognitions. Psychological and educational considerations* (Cambridge: Cambridge University Press, 1993).
Samuel, Raphael, 'The workshop of the world: steam power and hand technology in mid-Victorian Britain,' *History workshop journal* 3 (1977): 6-72.
Sarasohn, Lisa T., 'Nicolas-Claude Fabri de Peirsec and the patronage of the new science in the seventeenth century,' *Isis* 84:1 (1993): 70-90.
Schaffer, Simon, 'Babbage's dancer and the impresarios of mechanism,' F. Spufford and J. Uglow, eds., *Cultural Babbage: technology, time, and invention* (London: Faber and Faber, 1996), pp. 53-80.
Schaffer, Simon, 'Babbage's intelligence: calculating engines and the factory system,' *Critical inquiry* 21 (1994): 203-27.
Schaffer, Simon, 'Enlightened automata,' William Clark, Jan Golinski and Simon Schaffer, eds., *The sciences in enlightened Europe* (Chicago: University of Chicago Press, 1999), pp. 126-165.
Schaffer, Simon, 'Genius in romantic natural philosophy,' *Romanticism and the sciences*, eds., Andrew Cunningham and Nicholas Jardine (Cambridge: Cambridge University Press, 1990), pp. 82-98.
Schaffer, Simon, 'Glass works: Newton's prisms and the uses of experiment,' David Gooding, Trevor Pinch and Simon Schaffer, eds., *The uses of experiment. Studies in the natural sciences* (Cambridge: Cambridge University Press, 1989), pp. 67-104.
Schatzberg, Eric, '*Technik* comes to America,' *Technology and culture* 47 (2006): 486-512.
Schivelbusch, Wolfgang, *Disenchanted night: the industrialization of light in the nineteenth century*, trans. Angela Davies (Berkeley, CA: University of California Press, 1995).
Schmidt, J., ed., *What is Enlightenment? Eighteenth-century answers and twentieth-century questions* (Berkeley, CA: University of California Press, 1996).
Schneider, Wolfgang, *Geschichte der pharmazeutischen Chemie* (Weinheim: Verlag Chemie, 1972).
Schneider, Wolfgang, *Lexikon zur Arzneimittelgeschichte: Sachwörterbuch zur Geschichte der pharmazeutischen Botanik, Chemie, Mineralogie, Pharmakologie, Zoologie* (Framkfurt am Main: Govi, 1968-75, 7 vols.).
Schofield, Robert E., 'An evolutionary taxonomy of eighteenth-century Newtonianisms,' *Studies in eighteenth-century culture* 7 (1978): 175-192.
Schönherr, David v., 'Wenzel Jamnitzers arbeiten für Erzherzog Ferdinand,' Th. Ritter v. Sickel, H. Ritter v. Zeissberg, and E. Mühlbacher, eds., *Mitteilungen des Instituts für Oesterreichische Geschichtsforschung*, vol. 9 (Innsbruck: Verlag der Wagner'schen Universitäts-Buchhandlung, 1888), pp. 289-305 (Fascs. repr. Amsterdam: Swets & Zeitlinger, 1971).
Schuster, John A., 'Descartes and the scientific revolution 1618-1634: an interpretation' (Unpublished PhD dissertation, Princeton University, 1977).
Schuster, John A., 'Descartes *opticien*. The construction of the law of refraction and the manufacture of its physical rationales, 1618-29,' in Stephen Gaukroger et.al., eds., *Descartes' natural philosophy* (London: Routledge, 2000), pp. 258-312.
Schuster, John A., 'Descartes' mathesis universalis: 1619-1628,' in Stephen Gaukroger, ed., *Descartes: philosophy, mathematics and physics* (Sussex: The Harvester Press, 1980), pp. 41-96.
Scott, James, *Seeing like a state* (New Haven: Yale, 1998).
Scoville, Warren, *The persecution of Huguenots and French economic development, 1680-1720* (Berkeley and Los Angeles: University of California Press, 1960).
Segal, Ronald, *The Black Diaspora* (London: Faber and Faber, 1994).
Séris, Jean-Pierre, *Machine et communication* (Paris: Vrin, 1987).
Sewell, William H., *Work and revolution in France: the language of labor from the old regime to 1848* (Cambridge: Cambridge University Press, 1980).

Shapin, Steven and Simon Schaffer, *Leviathan and the air pump* (Princeton: Princeton University Press, 1985).
Shapin, Steven, 'The house of experiment in seventeenth-century England,' *Isis* 79 (1988): 373-404.
Shapin, Steven, 'A scholar and a gentleman: the problematic identity of the scientific practitioner in early modern England,' *History of science* 29 (1991): 279-327.
Shapin, Steven, 'Discipline and bounding: the history and sociology of science as seen through the internalism-externalism debate,' *History of science* 30 (1992): 333-369.
Shapin, Steven, 'Here and everywhere: sociology of scientific knowledge,' *Annual review of sociology* 21 (1995): 289-321.
Shapin, Steven, and Barry Barnes, 'Head and hand: rhetorical resources in British pedagogical writing, 1770-1850,' *Oxford review of education* 2 (1976): 231-54.
Shapin, Steven, *The Scientific Revolution* (Chicago: Chicago University Press, 1996).
Shea, William R., 'Descartes and the French artisan Jean Ferrier,' *Annali dell'Istituto e museo di storia della scienza di Firenze* 7 (1982): 145-160.
Shea, William R., *The magic of numbers and motion. The scientific career of René Descartes* (Canton: Science History Publications, 1991).
Shorter, A. H. *Paper making in the British isles: an historical and geographical study* (New York: Barnes and Noble, 1972).
Shorter, A. H., *Paper mills and paper makers in England, 1495-1800* (Hilversum: The Paper Publications Society, 1957).
Simmons, Anna, 'Medicines, monopolies and mortars: the chemical laboratory and pharmaceutical trade at the Society of Apothecaries in the eighteenth century,' Lissa Roberts and Rina Knoef, eds., *The places of chemistry in eighteenth-century Great Britain and the Netherlands,* special issue of *Ambix* 53 (2006): 221-236.
Simon, Jonathan*, Chemistry, pharmacy and revolution in France, 1777-1809* (Aldershot: Ashgate, 2005).
Siraisi, Nancy G., 'History, antiquarianism, and medicine: the case of Girolamo Mercuriale,' *Journal of the History of Ideas* 64 (2003): 231-251.
Sivin Nathan, and John Zhang, 'Steam power and networks in China 1860-98,' *History of Technology* 25 (2004): 203-10.
Sloan, Kim, 'Thomas Weston and the Academy at Greenwich,' *Transactions of the Greenwich and Lewisham Antiquarian Society* 9 (1984): 313-933.
Smiles, Samuel, ed., *James Nasmyth, engineer: an autobiography* (New York: Harper, 1883).
Smiles, Samuel, *Lives of the engineers*, 5 vols., Vol. 1: *Early engineering* (London: John Murray, 1874).
Smit, J., 'Achttiende eeuwse luchtvaartproeven in Den Haag,' *Jaarboek Die Haghe* (1914-15): 338-353.
Smith, Crosbie and Jon Agar, eds.*, Making space for science: territorial themes in the shaping of knowledge* (Basingstoke: Macmillan, 1998).
Smith, Graham, *Something to declare: one thousand years of customs and excise* (London: Harrop, 1980).
Smith, Pamela H. and Paula Findlen, eds., *Merchants and marvels: commerce, science and art in early-modern Europe* (London: Routledge, 2002).
Smith, Pamela H., *The body of the artisan: art and experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004).
Smith, Woodruff D., 'The function of commercial centers in the modernization of European capitalism: Amsterdam as an information exchange in the seventeenth century,' *The journal of economic history* 44 (1984): 985-1005.

Sohn-Rethel, Alfred, *Intellectual and manual labour: a critique of epistemology* (London: Macmillan, 1978).
Sonenscher, Michael, *Work and wages: natural law, politics and the eighteenth-century French trades* (Cambridge: Cambridge University Press, 1989).
Spary, Emma, 'Political, natural and bodily economies,' N. Jardine, J.A. Secord and E.C. Spary, eds., *Cultures of Natural History*, (Cambridge: Cambridge University Press, 1996), pp. 178-96.
Spragens, Thomas A., Jr., *The Politics of motion: the world of Thomas Hobbes* (Lexington: The University Press of Kentucky, 1973).
Staudenmaier, John, *Technology's storytellers* (Cambridge, ma: MIT Press, 1985).
Stechow, Wolfgang, *Northern Renaissance art 1400-1600: sources and documents* (Evanston, Ill: Northwestern University Press, 1989).
Steele, Brett and Tamera Dorland, eds., *The heirs of Archimedes: Science and the art of war through the age of Enlightenment* (Cambridge, ma: MIT Press, 2005).
Stewart, Larry, *The rise of public science: rhetoric, technology and natural philosophy in Newtonian Britain 1660-1750* (Cambridge: Cambridge University Press, 1992).
Stone, Lawrence, ed., *An imperial state at war: Britain from 1689 to 1815* (London: Routledge, 1994).
Stoot, W.F., 'Some aspects of naval architecture in the eighteenth century,' *Transactions of the Institution of Naval Architects* 101 (1959): 31-46.
Streefkerk, Chris, Jan Werner, and Frouke Wieringa, eds., *Perfect gemeten, landmeters in Hollands Noorderkwartier ca. 1550-1700* (Alkmaar: Stichting Uitgeverij Noord-Holland, 1994).
Striebel, Ernst, 'Über das färben von Holz, Horn und Bein. Das Augsburger kunstbuechlin von 1535,' *Restauro* 6 (2003): 424-30.
Stromer, Wolfgang von, "Zur 'ars artificialiter scribendi' und weiteren 'künsten' der Waldfoghel aus Prag und Girard Ferroses aus Trier, Nürnberg 1433-34 und Avignon 1444-46, *Technikgeschichte*, 49 (1982): 279-289.
Stürzbecher, Manfred, *Beiträge zur Berliner Medizingeschichte: Quellen und Studien zur Geschichte des Gesundheitswesens vom 17. bis zum 19. Jahrhundert* (Berlin: Walter de Gruyter, 1966).
Stürzbecher, Manfred, *Berlins alte Apotheken* (Berlin: Bruno Hessling, 1965).
Summers, Dorothy, *The Great Level: a history of drainage and land reclamation in the Fen*s (Newton Abbot and London: David & Charles, 1976).
Sumner, James, 'John Richardson, saccharometry and the pounds-per-barrel extract: the construction of a quantity,' *British journal for the history of science* 34 (2001): 255-273.
Sumner, James, 'The metric tun: standardisation, quantification and industrialisation in the British brewing industry, 1760-1830' (unpublished PhD, University of Leeds, 2004).
Sutherland, J., *Victorian fiction: writers, publishers, readers* (London: MacMillan, 1995).
Swade, D., 'The construction of Charles Babbage's Difference Engine No. 2,' *IEEE Annals of the history of computing* 27 (2005): 70-88.
Tafuri, Manfredo, 'Scienza, politica e architettura,' Tafuri, *Venezia e il Rinascimento* (Turin: Einaudi, 1985).
Tate, F. G. H., *Alcoholometry: an account of the British method of alcoholic strength determination* (London: HMSO, 1930).
Taverne, Ed, *In 't land van belofte: in de nieue stadt; ideaal en werkelijkheid van de stadsuitleg in de Republiek 1580-1680* (Maarssen: Gary Schwartz, 1978).
Taylor, Rabun, *Public needs and private pleasures* (Rome: L'Erma Bretschneider, 2000).
Thirsk, Joan, *Economic policy and projects: the development of a consumer society in early modern England* (Oxford: Clarendon Press, 1978).

Thirsk, Joan, *English peasant farming: the agrarian history of Lincolnshire from Tudor to recent times* (London: Routledge & Kegan Paul, 1957).

Thirsk, Joan, gen. ed., *The agrarian history of England and Wales*, 8 vols., Vol. V, pt. II: *1640-1750, agrarian change* (Cambridge: Cambridge University Press, 1985).

Thompson, E.P., 'The moral economy of the English crowd in the eighteenth century,' E.P. Thompson, *Customs in common* (New York: New Press, 1993): 185-258.

Thompson, E.P., *Witness against the beast: William Blake and the moral law* (Cambridge: Cambridge University Press, 1993).

Thomson, James, 'Invention in the Industrial Revolution,' Leandro Prados de la Escosura, ed., *Exceptionalism and industrialisation: Britain and its European rivals, 1688-1815* (Cambridge: Cambridge University Press, 2004), pp. 127-144.

Tilly, Charles *Politics of collective violence* (New York: Cambridge University Press, 2003).

Tilly, Charles, *Contention and democracy in Europe 1650-2000* (New York: Cambridge University Press, 2004).

Trentman, Frank, 'National identity and consumer politics: free trade and tariff reform,' R. Floud and D. Johnson eds., *The Cambridge economic history* (Cambridge: Cambridge University Press, 2nd edition., 1995), pp. 215-42.

Tribby, Jay, 'Cooking (with) Clio and Cleo: eloquence and experiment in seventeenth-century Florence,' *Journal of the history of ideas* 52 (1991): 417-439.

Tribe, Keith, *Land, labour and economic discourse* (London: Routledge, 1978).

Tunzelmann, G.N. von, 'Technological and organizational change in industry during the Industrial Revolution,' Patrick O'Brien and Roland Quinault, eds., *The Industrial Revolution and British society* (Cambridge: Cambridge University Press, 1993), pp. 254-82.

Turnbull, David, *Masons, tricksters and cartographers: comparative studies in the sociology of scientific and indigenous knowledge* (Amsterdam: Harwood, 2000).

Uglow, Jenny, *The lunar men: the friends who made the future* (London: Faber and Faber, 2002).

Umesao T., James Bartholomew and Shigeharu Sugita, eds., *Japanese civilization in the modern world: Vol. 10, Technology* (Kyoto: National Museum of Ethnology, 1998).

Unger, Richard, 'Design and construction of European warships in the seventeenth and eighteenth centuries,' M. Arrera, J. Merino and J. Meyer, eds., *Les marines de guerre européennes XVII-XVIII^{e} siècles* (Paris: Presses Universitaires de Paris-Sorbonne, 1986), pp. 21-34.

Valleriani, Mattei, 'A view on Galileo's *Ricordi autografi*. Galileo practitioner in Padua,' José Montesinos and Carlos Solis, eds., *Largo campo di filosofare. Eurosymposium Galileo 2001* (La Orotava: Fundación Canaria Orotava de Historia de la Ciencia, 2001), pp. 281-291.

Van Fraassen, Bas C., *The scientific image* (Oxford: Clarendon Press, 1980).

Ven, G.P. van de, ed., *Man-made Lowlands; history of water management and land reclamation in the Netherlands* (Utrecht: Matrijs, 2004, first in Dutch 1993).

Verbruggen, Jan, 'The correspondence of Jan Daniel Huichelbos van Liender with James Watt' (PhD thesis, Universiteit Twente, 2005).

Vérin, Hélène, 'Technology in the park: engineers and gardeners in seventeenth-century France,' *The architecture of western gardens; a design history from the Renaissance to the present day*, eds., M. Mosser and G. Teyssot (Cambridge, ma: MIT Press, 1991), pp. 135-146.

Vérin, Hélène, *La gloire des ingénieurs: l'intelligence technique du 16^{e} au 18^{e} siècle* (Paris: Albin Michel, 1993).

Vermij, Rienk, 'Een nieuw concept: de wetten der natuur,' Florike Egmond et.al. ed., *Kometen, monsters en muilezels. Het veranderende natuurbeeld en de natuurwetenschap in de zeventiende eeuw* (Haarlem: Uitgeverij Arcadia, 1999), pp. 105-119.

Vershofen, Wilhelm, *Die anfänge der Chemisch-Pharmazeutischen industrie* (Berlin/Stuttgart: Deutscher Betriebswirte-Verlag, 1949, 2 vols.).
Vitruvius, *Ten books on architecture*, ed., Henry Langford Warren (Cambridge, MA: Harvard University Press, 1914).
Vries, Jan de, 'Between purchasing power and the world of goods: understanding the household economy in early modern Europe,' John Brewer and Roy Porter eds., *Consumption and the world of goods*, pp. 85-132.
Vries, Jan de, 'Economic growth before and after the Industrial Revolution,' M. Prak, ed., *Early modern capitalism. Economic and social change in Europe 1400-1800* (London: Routledge, 2001), pp. 177-194.
Vries, Jan de, and Ad van der Woude, *Nederland 1500-1815, De eerste ronde van moderne economische groei* (Amsterdam: Balans, 2005).
Vries, Jan de, *The economy of Europe in an age of crisis 1600-1750* (Cambridge: Cambridge University Press, 1976).
Ward-Perkins, Bryan, *From Classical Antiquity to the Middle Ages* (Oxford, Oxford University Press, 1984).
Waterbury John, *Hydropolitics of the Nile Valley* (Syracuse: Syracuse University Press, 1979).
Watson-Verran, Helen and David Turnbull, 'Science and other indigenous knowledge systems,' Sheila Jasanoff, Gerald E. Marble, James C. Peterson and Trevor Pinch, eds., *Handbook of science and technology studies* (London: Sage Publications, 1995), pp. 115-139.
Wells, Samuel, *The history of the drainage of the Great Level of the Fens, called Bedford Level; with the constitution and laws of the Bedford Level Corporation*, 2 vols. (London: R. Pheney, 1828-1830).
Wenzel Jamnitzer und die Nürnberger goldschmiedekunst 1500-1700, Catalog of the Germanisches Nationalmuseum, Nuremberg (Munich: Klinkhardt & Bierman, 1985).
Wharam, Alan, *The treason trials, 1794* (Leicester: Leicester University Press, 1992).
Wharam, Alan, *Treason: famous English treason trials* (Stroud: Alan Sutton, 1995).
Wielema, Michiel R., 'Hartsoeker, Nicolaas (1656-1725),' Wiep van Bunge et.al. eds., *The dictionary of seventeenth and eighteenth-century Dutch philosophers* 2 vols., Vol. I (Bristol: Thoemmes Press, 2003), pp. 389-390.
Wielema, Michiel R., 'Nicolaas Hartsoeker (1656-1725): van mechanisme naar vitalisme,' *Gewina* 15 (1995): 243-261.
Williams, J., 'Mathematics and the alloying of coinage 1202-1700,' *Annals of science* 52 (1995): 213-234.
Williams, Raymond, *Culture and society 1780-1950* (1958; Harmondsworth: Penguin, 1961).
Willmoth, Frances, *Sir Jonas Moore: practical mathematics and restoration science* (Woodbridge, Suffolk: The Boydell Press, 1993).
Wilson, Charles, *Anglo-Dutch commerce and finance in the eighteenth century* (Cambridge: Cambridge University Press, 1941).
Wilson, Charles, *England's apprenticeship 1603-1763* (London: Longmans, 1966).
Winch, Donald and O'Brien, Patrick K., eds., *The political economy of British historical experience* (Oxford: Oxford University Press, 2003).
Winter, P.J. van, *Hoger beroepsonderwijs avant-la-lettre. Bemoeiingen met de vorming van landmeters en ingenieurs bij de Nederlandse universiteiten van de 17e en 18e eeuw.* Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, afd. Letterkunde, 137 (1988).
Wise, M. Norton, ed., *The values of precision* (Princeton: Princeton University Press, 1995).

Wittfogel, Karl, *Oriental despotism: a comparative study of total power* (New Haven: Yale University Press, 1957).
Woordenboek der Nederlandsche Taal (Den Haag: SDU, 1993-2001).
Wright, Thomas, 'Mark Beaufoy's nautical and hydraulic experiments,' *Mariner's Mirror* 75 (1989): 313-27.
Yue, Meng, 'Hybrid science versus modernity: the practice of the Jiangnan arsenal 1864-1897,' *EASTM* 16 (1999): 13-52.
Zammito, John H., *A nice derangement of epistemes: post-positivism in the study of science from Quine to Latour* (Chicago: University of Chicago Press, 2004).
Zilsel, Edgar, 'The sociological roots of science,' *American journal of sociology* 47 (1942): 544-62.
Zilsel, Edgar, 'The social origins of modern science', ed., Diederick Raven, Wolfgang Krohn and Robert S. Cohen, *Boston studies in the philosophy of science*, vol. 200 (Dordrecht: Kluwer, 2000).
Zinsser, Judith, ed., *Men, women and the birthing of modern science* (DeKalb: Northern Illinois University Press, 2005).

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