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Instruments of statecraft: Humphrey Cole, Elizabethan economic policy and the rise of practical mathematics

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ABSTRACT

This paper offers a re-interpretation of the development of practical mathematics in Elizabethan England, placing artisanal know-how and the materials of the discipline at the heart of analysis, and bringing attention to Tudor economic policy by way of historical context. A major new source for the early instrument trade is presented: a manuscript volume of Chancery Court documents c.1565–c.1603, containing details of a patent granting a monopoly on making and selling mathematical instruments, *circa* 1575, to an unnamed individual, identified here as the instrument maker Humphrey Cole. Drawing on economic and legal history, the paper argues that practical mathematics needs to be understood as one 'project' among many, at a time when monopoly patents were used to advance industry, lower unemployment, secure the realm and reward invention. Drawing on the history and sociology of technology, it argues that the management and control of materials – mathematical instruments themselves, and the local socio-legal context within which they could be made – needs to be understood as prior to and separate from the rhetoric of mathematical authors, which is of interest in its own right but which may not have a direct relationship to mathematical practice.

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Contents

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1. Introduction

The rise of 'practical mathematics', first on the Continent and then through the sixteenth century in England, is now well known as an important episode in the history of early-modern science. This broad set of linked disciplines – also known as 'the Mathematicalls', 'mixed mathematics', or 'the mathematical arts' – has been attractive to historians because it brings together a wide range of activities, involves a large corpus of complex and ingenious instruments, and connects scholars, craftsmen and the nobility to the work of navigators, gunners, architects, surveyors and astrologers.[1] In treatments as diverse as Deborah Harkness' popular *The Jewel House*, Eric Ash's polemical *Power, Knowledge, and Expertise in Elizabethan England*, and extensive and fine-grained studies by Jim Bennett, Mario Biagioli, David Bryden, Gloria Clifton, Lesley Cormack, Stephen Johnston, Gerard Turner and others, a picture has emerged of invention, technique, trade, patronage, and a subtly graded social hierarchy of practitioners vying for preferment and commercial success.[2] There is plenty at stake in these accounts. The paths taken by many scholars lead to such things as the development of experimental philosophy, 'the mechanical philosophy', Heliocentrism, Baconianism, Cartesianism, Newtonianism, and (therefore) a large number of other topics for which it is provocative and exciting to find practical and material antecedents.[3] As Stephen Pumfrey has put it, the question posed by the rise of practical mathematics is

[1]The foundational work for the English case is E. G. R. Taylor, *The Mathematical Practitioners of Tudor and Stuart England* (Cambridge: Cambridge University Press, 1954).

[2]Deborah Harkness, *The Jewel House: Elizabethan London and the Scientific Revolution* (New Haven, CT and London: Yale University Press, 2007); Eric H. Ash, *Power, Knowledge, and Expertise in Elizabethan England* (Baltimore, MD: Johns Hopkins University Press, 2004); Jim Bennett, 'The Challenge of Practical Mathematics', in *Science, Culture and Popular Belief in Renaissance Europe*, ed. by Stephen Pumfrey, Paolo L. Rossi and Maurice Slawinski (Manchester and New York: Manchester University Press, 1991), pp. 176–90; Mario Biagioli, 'From Print to Patents: Living on Instruments in Early Modern Europe', *History of Science* 44 (2006), 139–86; David J. Bryden, 'Evidence from Advertising for Mathematical Instrument Making in London, 1556–1714', *Annals of Science* 49 (1992), 301–36; Gloria Clifton, *Directory of British Scientific Instrument Makers, 1550–1851* (London: Philip Wilson, 1994); Lesley B. Cormack, 'Mathematics for Sale: Mathematical Practitioners, Instrument Makers, and Communities of Scholars in Sixteenth-Century London', in *Mathematical Practitioners and the Transformation of Natural Knowledge in Early Modern Europe*, ed. by Lesley B. Cormack, Steven A. Walton and John A. Schuster (Cham: Springer, 2017), pp. 69–85; Stephen Johnston, 'Making Mathematical Practice: Gentlemen, Practitioners and Artisans in Elizabethan England' (unpublished PhD thesis, University of Cambridge, 1994); Gerard L'E. Turner, *Elizabethan Instrument Makers: The Origins of the London Trade in Precision Instrument Making* (Oxford: Oxford University Press, 2000).

[3]For experimental philosophy see Edgar Zilsel, 'The Sociological Roots of Science', *American Journal of Sociology* 47 (1942), 544–62, and, for context, Wolfgang Krohn and Diederick Raven, 'The "Zilsel Thesis" in the Context of Edgar Zilsel's Research Programme', *Social Studies of Science* 30 (2000), 925–33; for mechanical philosophy see Jim Bennett, 'The Mechanics' Philosophy and the Mechanical Philosophy', *History of Science* 24 (1986), 1–28; for Heliocentrism (specifically its acceptance) see Bruce T. Moran, 'Christoph Rothmann, The Copernican Theory, and Institutional and Technical Influences on the Criticism of Aristotelian Cosmology', *The Sixteenth Century Journal* 13 (1982), 85–108; for Baconianism see Cesare Pastorino, 'The Philosopher and the Craftsman: Francis Bacon's Notion of Experiment and Its Debt to Early Stuart Inventors', *Isis* 108 (2017), 749–68; for Cartesianism see John A. Schuster, 'Consuming and Appropriating Practical Mathematics and the Mixed Mathematical Fields, or Being "Influenced" by Them: The Case of the Young Descartes', in *Mathematical Practitioners*, ed. by Cormack, Walton and Schuster, pp. 37–65; for Newtonianism see Boris Hessen, 'The Social and Economic Roots of Newton's *Principia*', in *Science at the Cross Roads*, ed. by P.G. Werskey (London: Frank Cass., 1971; 1st edn 1931), pp. [146]–209, and, for context, Simon Schaffer, 'Newton at the Crossroads', *Radical Philosophy* 37 (1984), pp. 23–8.

> central to our understanding of the modern historical epoch: how did scientific experts and technocrats acquire the power through which they have persuaded us to understand the world in terms of universal laws and instrumental reason rather than our personal and local experience of nature?[4]

In spite of this – and perhaps owing to the fact that it serves as an 'origin' for other things – practical mathematics lacks a sophisticated explanatory framework of its own. Underlying many older accounts is the idea that mathematical techniques were necessitated by military and naval developments, changes in land ownership, population, and governance.[5] Ultimately these explanations rely on one or both of two assumptions: first, that mathematical techniques triumphed owing to their inherent superiority; second, that the agency for change lay in the hands of a few brilliant, highly educated and ambitious experts who cleaved a position between statesmen and artisans and brought the mathematical project to fruition.[6]

Countering this, more subtle analyses of mathematical practice have shown how complex and variegated the mathematical community was, how dependent it was on networks of patronage and commerce, how rhetoric did not necessarily translate into practice, how instruments that might appear useful were often ornamental, and how new techniques, once proposed, might take decades to have any influence on the disciplines they were supposed to reform.[7] Add to this the difficulty of knowing precisely how mathematical knowledge was utilized in armed combat, navigation, surveying, or architecture, and the scarcity of evidence relating to the crucial issue of mathematical pedagogy, and the overall picture – whilst remaining vivid in terms of surviving instruments and books – becomes far less easy to discern.[8]

In part, of course, this is the result of sources that are patchy and difficult to interpret. For mathematical instruments, for instance, these can be broadly divided into three kinds. First, instruments themselves provide much of our information, and were invaluable to the first antiquarians who paid attention to developments in post-mediaeval practical mathematics.[9] Second, printed

[4]Stephen Pumfrey, 'Review of Eric H. Ash, *Power, Knowledge, and Expertise in Elizabethan England*', *The Journal of Modern History*, 80 (2008), 130–2, quotation 130–1.

[5]The canonical statement of this is given in Turner, *Elizabethan Instrument Makers*, ch. 1.

[6]The latter, in particular, is the line pursued in Ash, *Power, Knowledge, and Expertise*.

[7]See, respectively, Stephen Johnston, 'The Identity of the Mathematical Practitioner in Sxteenth-Century England', in *Der "mathematicus": Zur Entwicklung und Bedeutung einer neuen Berufsgruppe in der Zeit Gerhard Mercators*, ed. by Irmgarde Hantsche (Bochum: Brockmeyer, 1996), pp. 93–120; Stephen Pumfrey and Frances Dawbarn, 'Science and Patronage in England, 1570–1625: A Preliminary Study', *History of Science* 42 (2004), 137–88; Steven A. Walton, 'Technologies of Pow(d)er: Military Mathematical Practitioners' Strategies and Self-Presentation', in *Mathematical Practitioners*, ed. by Cormack, Walton and Schuster, pp. 87–113; Jim Bennett, 'Presidential Address: Knowing and Doing in the Sixteenth Century: What Were Instruments For?', *The British Journal for the History of Science* 36 (2003), 129–50; Jim Bennett, 'Geometry and Surveying in Early Seventeenth-Century England', *Annals of Science* 48 (1991), 345–54.

[8]On the complexities of (and options and sources for) interpreting pedagogy, see Adam Mosley, 'Introduction: Objects, Texts and Images in the History of Science', *Studies in History and Philosophy of Science* 38 (2007), 289–302, and the essays contained in that special issue.

[9]On the use of instruments to reconstruct sixteenth-century practical mathematics see Stephen Johnston, 'Mathematical Practitioners and Instruments in Elizabethan England', *Annals of Science* 48 (1991), 319–44.

sources are also important, not only the many maps and engravings by mathematical instrument makers, but also the advertisements for their services and the books that accompanied new devices.[10] The third and final major source of information on the early trade is official documentation, mainly guild records. These have cast light on previously obscure areas, in particular master-apprentice relationships.[11] Quite quickly, it seems, instrument makers were absorbed into already-existing guilds, only really breaking free of the restrictions of those organizations much later. Other kinds of information on the trade are vanishingly scarce: a list of instruments taken on board ship here; a manuscript account of an instrument there.[12]

But the issue is also methodological. Instrument studies has emerged relatively slowly from its antiquarian origins. Economic history and legal history, for example, have had only a negligible effect on studies of the instrument trade. Another striking absence is any sustained dialogue between instrument experts and historians and sociologists of technology. With only a few exceptions, the insights of the latter have not been brought to bear on the technical knowledge of the former, and this situation is particularly bad for the early-modern period.

In this paper I offer a re-interpretation of the development of practical mathematics in Elizabethan England, placing artisanal know-how and the materials of the discipline at the heart of analysis, and bringing attention to Tudor economic policy by way of historical context.[13] I present a major new source for the early instrument trade – a manuscript volume of Chancery Court documents c.1565–c.1603, containing details of a patent granting a monopoly on making and selling mathematical instruments, *circa* 1575, to an unnamed individual, whom I identify as the instrument maker Humphrey Cole.[14] Drawing on economic and legal history, I argue that practical mathematics needs to be understood as one 'project' among many in what Joan Thirsk has called 'the constructive phase of projects, 1540–1580', when monopoly patents were used to advance industry, lower unemployment, secure the realm and reward invention.[15] Drawing on the

[10]On the relationship between instrument making and engraving for print see Turner, *Elizabethan Instrument Makers*, ch. 3, and David. J. Bryden, 'The Instrument Maker and the Printer: Paper Instruments Made in Seventeenth Century London', *Bulletin of the Scientific Instrument Society* 55 (1997), 3–15; for advertisements see Bryden, 'Evidence from Advertising'; for instrument books see Katie Taylor, 'A "Practique Discipline"? Mathematical Arts in John Blagrave's *The Mathematical Jewel* (1585)', *Journal for the History of Astronomy* 41 (2010), 329–54; Adam Mosley, 'Introduction', p. 293ff.

[11]See Joyce Brown, 'Guild Organisation and the Instrument-Making Trade, 1550–1830: The Grocers' and Clockmakers' Companies', *Annals of Science* 36 (1979), 1–34; Joyce Brown, *Mathematical Instrument Makers in the Grocers' Company* (London: The Science Museum, 1979); Michael A. Crawforth, 'Instrument Makers in the London Guilds', *Annals of Science* 44 (1987), 319–77.

[12]An early example is the manuscript description of a ring dial made by William Buckley for the then Princess Elizabeth in 1546; see Taylor, *Mathematical Practitioners*, p. 314; the list of instruments taken on board Frobisher's voyage is discussed in the body of the text below.

[13]On Cole see Silke Ackermann (ed.), *Humphrey Cole: Mint, Measurement and Maps in Elizabethan England* (London: The British Museum, 1998).

[14]See Biagioli, 'From Print to Patents'.

[15]Joan Thirsk, *Economic Policy and Projects: The Development of a Consumer Society in Early Modern England* (Oxford: Oxford University Press, 1978), ch. 2, esp. p. 33ff.

history and sociology of technology, I argue that the management and control of materials – mathematical instruments themselves, and the local socio-legal context within which they could be made – needs to be understood as prior to and separate from the rhetoric of mathematical authors, which is of interest in its own right but which may not have a direct relationship to mathematical practice.

In light of this, we can see the 1570s as a decisive decade in the development of practical mathematics in England. It was at this point that instrument making shifted from private networks of craft and patronage to public networks of trade and commerce. This is based on a straightforward observation, which has in fact been hiding in plain sight: prior to the successful development of Cole's workshop (coinciding with the patent), instruments were made only by isolated individuals working on commission and mainly with court patronage in mind; yet within a decade of the patent an extensive market for instruments had been established in London, with makers differentiated by the uses to which their instruments could be put and the materials in which they worked. Owing to the particular source referred to here (the patent) and the individual identified as its beneficiary (Cole), the argument is quite closely focused and in part biographical. However, on the one hand I see no problem in restoring agency to a member of an artisanal class often neglected in histories that have focused on the literary output of the landed gentry; and, on the other, my argument is as much about statecraft and the Elizabethan notion of the encouragement of trades as it is about the role of a particular individual within that system. It was, I argue, the specific and successfully realized intention to create a monopoly in instrument making that permitted Humphrey Cole to play a crucial role in establishing a vibrant and diverse trade in instruments, and the establishment of that trade in turn brought the highly differentiated world of the 'mathematical practitioner' into being.[16]

The paper begins with a summary of what is known about the development of the instrument trade in England in the sixteenth century, before turning to the context and content of the patent document. This concerns the making of a specific instrument, the cross-staff, an account of which is then given. I turn next to the question of the patentee's identity, arguing that Cole was its recipient; the implications of this are considered, leading to a discussion of patenting and the nature of commerce in Elizabethan England, and (in conclusion) methodological reflections on the historical study of practical mathematics.

[16]On the identity of the 'mathematical practitioner' see Johnston, 'The Identity of the Mathematical Practitioner'; Katherine Hill, '"Juglers or Schollers?' Negotiating the Role of a Mathematical Practitioner', *The British Journal for the History of Science British Society for the History of Science* 31 (1998), 253–74; Hester Higton, 'Does Using an Instrument Make You Mathematical? Mathematical Practitioners of the 17th Century', *Endeavour* 25 (2001), 18–22.

2. The development of the instrument trade

The story of the early English trade in mathematical instruments is well studied and has achieved relatively settled status.[17] Practical mathematics developed earlier on the continent, particularly in Italy, France, the German lands and the Low Countries.[18] Through the sixteenth century two pioneering craftsmen – Nicholaus Kratzer and Thomas Gemini – brought their expertise to London, seeking patronage and working in relative isolation. Kratzer was court astronomer to Henry VIII and is now best known for his collaborations with the painter Hans Holbein the Younger, in addition to the few of his sundials that have survived.[19] Gemini was a more prolific and skilled artisan – his astrolabes are amongst the finest early instruments – and he was closer to what soon became an established trade.[20] While Kratzer had pursued a career at court and amongst Oxford's colleges, Gemini engraved the plates for books, was involved in publishing, and became an active player in the cosmopolitan world of the livery companies.[21] Indeed it is the guilds that provide the link to the next generation of instrument makers – Humphrey Cole first amongst them – who began to establish a separate trade: advertising their wares, joining a variety of guilds (Grocers', Joiners', Goldsmiths') and continuing the tradition established by Gemini of supplementing their mathematical work with book and map engraving. By the end of the sixteenth century a reasonably large community of instrument makers supplied a range of customers, including merchants, gentlemen, artisans and scholars. In London it was possible to buy instruments for surveying, navigation, gunnery, astronomy, architecture, technical drawing, timetelling and other more obscure tasks. The class of 'mathematical instruments' was well defined and was dominated by instruments with divided scales and engraved projections – the techniques of trigonometry were common to many

[17]See Gerard L'E. Turner's essay 'Mathematical Instrument-Making in London in the Sixteenth Century', in *English Map-Making 1500–1650,* ed. by Sarah Tyacke (London: The British Library, 1983), pp. 93–106, which forms the basis of his *Elizabethan Instrument Makers*.

[18]See for example (for an overview) Judith V. Field and Frank A. J. L. James (eds.), *Renaissance and Revolution: Humanists, Scholars, Craftsmen, and Natural Philosophers in Early Modern Europe* (Cambridge: Cambridge University Press, 1993); (for Italy) Silvio A. Bedini, *Science and Instruments in Seventeenth-Century Italy* (Aldershot: Ashgate, 1994); (for France) Alexander Marr (ed.), *The worlds of Oronce Fine: Mathematics, Instruments and Print in Renaissance France* (Donington: Shaun Tyas, 2009); (for the German Lands) Giorgio Strano, Stephen Johnston, Mara Miniati and Alison Morrison-Low (eds), *European Collections of Scientific Instruments, 1550–1750* (Leiden and Boston, MA: Brill, 2009); (for the Low Countries) Koenraad Van Cleempoel, *A Catalogue Raisonné of Scientific Instruments from the Louvain School, 1530 to 1600* (Turnhout: Brepols Publishers, 2002).

[19]On Kratzer see John D. North, 'Nicholaus Kratzer – The King's Astronomer', in Erna Hilfstein, Pawel Czartoryski and Frank D. Grande (eds), *Science and History: Studies in Honor of Edward Rosen*, Studia Copernica Vol. XVI (Warsaw, Krakow and Gdansk: Ossolineum, The Polish Academy of Sciences Press, 1978), pp. 205–34; W. D. Hackmann, 'Nicholaus Kratzer: The King's Astronomer and Renaissance Instrument-Maker', in David Starkey (ed.), *Henry VIII: A European Court in England* (London: Collins and Brown, 1991), pp. 70–3 and 152–3; on Kratzer's sundials see Peter Drinkwater, *The Sundials of Nicholaus Kratzer* (Shipston-on-Stour: the author, 1993).

[20]See Robert T. Gunther, 'The Astrolabe of Queen Elizabeth', *Archaeologia* 86 (1937), 65–72; Peter Murray Jones, 'Gemini [Geminus, Lambrit], Thomas (*fl.* 1540–1562)', *Oxford Dictionary of National Biography* <https://doi.org/10.1093/ref:odnb/10513> [accessed 4 September 2018]. Gemini's astrolabes survive in the collections of the Museum for the History of Science, Oxford (42223), the National Maritime Museum, Greenwich (AST0567 – mater only) and the Observatoire Royale de Belgique, Brussels (IC 450).

[21]See Turner, *Elizabethan Instrument Makers*, pp. 12–20.

instruments, and mathematical authors produced books explaining specific inventions and relating them to the underlying principles of arithmetic and geometry.

Establishing the number of instrument makers working in London at this time is a complex matter, owing to a dearth of surviving instruments and ambiguity over whether those who sold instruments actually made them. In his survey *Elizabethan Instrument Makers*, Gerard Turner identified 19 craftsmen working in that period.[22] In the database of instrument makers begun by Turner and Michael Crawforth and maintained by Gloria Clifton – 'Scientific Instrument Makers, Observations and Notes' (SIMON) – 22 instrument makers are listed before 1600. Lesley Cormack raises this to 26 instrument makers working between 1550 and 1600.[23] As we will see below, this date-range needs to be further subdivided in light of my argument for two phases of development, pre and post 1575. For clarity, and for reference in what follows, Table 1 shows the names and details of those certainly known to have made instruments between 1550 and 1600.

I return to analysis of this table in Section 3.3 below. For now it will suffice to note that Cole is very obviously in a pivotal position. Prior to him there are only a handful of makers, who were highly specialized and worked for private clients. Cole's exact contemporaries were a clockmaker and compass-maker, the former presumably working to commission from his patrons, and the latter likely never to have made mathematical instruments at all. After Cole's first period of productivity (c.1565–c.1575) there appear more than a dozen makers with premises in London to which interested visitors could come and purchase a wide range of instruments. It is the purpose of the present essay to offer an explanation of this change.

The structure of the trade and reasons for this development are not well understood. From the end of the sixteenth century we have reasonably good records for master-apprentice lineages, the earliest known being Augustine Ryther and Charles Whitwell, while the latter was master to Elias Allen, who in turn began one of the great craft traditions of the seventeenth century.[24] Yet, though the guilds certainly welcomed instrument makers and by their very nature supported the craft, there is no suggestion that they played a strong role in fostering or advancing practical mathematics more generally, or stimulating new developments in instrument making (for example, the adoption of new kinds of instruments or the expansion to new markets).

As mentioned above, the rise of practical mathematics has typically been attributed to the necessity for mathematically grounded, technologically

[22]Ibid., esp. pt. II, but see in particular the chart at p. 7. Turner also identifies 12 unattributed instruments as dating from the Elizabethan period.

[23]Cormack, 'Mathematics for Sale', p. 78.

[24]On the Allen lineage see Brown, 'Guild Organisation', p. 10ff; for Allen's training, career and importance see Hester Higton, 'Elias Allen and the Role of Instruments in Shaping the Mathematical Culture of Seventeentli-Century England' (unpublished PhD thesis, University of Cambridge, 1996).

Table 1. Instrument makers known to have been working in London, 1550–1600.

	Name	Earliest date[a]	Latest date	Notes
1.	Thomas Gemini	c.1540	1562†	Multiple sources; see above
2.	William Buckley	1546	1551	Ring dial (lost) and astronomical quadrant[b]
3.	Richard Chancellor	c.1550	1556†	Recommendations of John Dee and Thomas Digges[c]
4.	'V.C'	c.1554	1557	Two astronomical compendia[d]
5.	Robert Norman*	c.1560	c.1584	Multiple sources;[e] compass maker
6.	Bartholomew Newsam	c.1565	1593†	Multiple sources;[f] clock and dial-maker to Queen Elizabeth I
7.	Humphrey Cole	1568	1590[g] (died 1591)	Multiple sources; see below
8.	William Thomas*	c.1576	c.1576	SIMON; compass maker
9.	Anthony Rumbridge*	1577	1577	Instrument maker on board the Ayde, Frobisher's 2nd voyage[h]
10.	James Lockerson*	1582	1582	Worsop;[i]
11.	John Read*	1582	1616	Worsop; Blagrave;[j] Lucar[k]
12.	John Reynolds*	1582	1590	Worsop; Lucar
13.	John Bull*	1582	1582	Worsop
14.	Augustin Ryther	1585	1593	Multiple sources;[l] master to Charles Whitwell (below)
15.	James Kynvyn	c.1582	c.1600	Harvey;[m] numerous instruments
16.	Christopher Paine*	1590	1590	Lucar
17.	Emery Molyneux	1592	1598†	Multiple sources[n]
18.	Thomas Osborne*	c.1593	c.1593	Fale;[o] may not have been a commercial instrument maker
19.	Charles Whitwell	1593	1611†	Multiple sources;[p] apprentice to Augustin Ryther (above)
20.	Francis Cooke*	1596	1596	Hood;[q] possibly a retailer rather than a maker of instruments[r]
21.	Robert Beckit	1597	1598	A single sector;[s] maps engraved in 1598
22.	Robert Grinkin	c.1598	1626†	Multiple sources;[t] primarily a watchmaker
23.	David Anderson*	1597	1597	SIMON

(*Continued*)

mediated responses to changing socio-economic situations, specifically involving the requirements of land surveying, gunnery, navigation and positional astronomy (including astrology and time-telling). The question remains, by whom and in what ways were the mathematical arts brought to bear on these domains? The answer typically given follows the rhetoric of the authors of mathematical treatises themselves, who argued for the utility of mathematics to the requirements of the commonwealth, and either implicitly or explicitly placed

Table 1. Continued.

	Name	Earliest date[a]	Latest date	Notes
24.	William Senior	1600	c.1641	A single horary quadrant;[u] also recorded as a surveyor

Notes: † = year of death. * = no surviving instruments. SIMON = Scientific Instrument Makers Online; electronic database accessible at the Royal Observatory, Greenwich.
[a]Earliest and latest dates record *working* dates, i.e. when the individual was known or likely to have been making instruments.
[b]See Taylor, *The Mathematical Practitioners*, pp. 169, 314.
[c]Taylor, *The Mathematical Practitioners*, p. 170.
[d]Compendia at the Museum of the History of Science, Oxford, inv. no. 51738, and Adler Planetarium, Chicago, inv. no. M-363.
[e]Jim Bennett, 'Norman, Robert (*fl.* 1560–1584)', *Oxford Dictionary of National Biography* <https://doi.org/10.1093/ref:odnb/20260> [accessed 4 September 2018].
[f]Adrian Finch, 'Newsam [Nusam, Newsham], Bartholomew (c. 1530–1587)', *Oxford Dictionary of National Biography* <https://doi.org/10.1093/ref:odnb/20040> [accessed 4 September 2018].
[g]An astronomical compendium by Cole dated 1590 has recently come to light. Many thanks to Silke Ackermann and Louise Devoy for this information.
[h]William W. Fitzhugh and Jacqueline S. Olin (eds), *Archeology of the Frobisher Voyages* (Washington, DC and London: Smithsonian Institution Press, 1993), p. 243.
[i]'An advertisement to the reader', in *Edward Worsop, A Discoverie of Sundrie Errours and Faults Daily Committed by Landmeters Ignorant of Arithmeticke and Geometrie* (London, 1582), sig. A4[r].
[j]John Blagrave, *Baculum Familliare, Catholicon sive Generale […]* (London, 1590), p. 69.
[k]Cyprian Lucar, *A Treatise Named Lucar Solace […]* (London, 1590), pp.9–10.
[l]Elizabeth Baigent, 'Ryther, Augustine (*d.* 1593)', *Oxford Dictionary of National Biography* <https://doi.org/10.1093/ref:odnb/24428> [accessed 4 September 2018].
[m]Marginal annotation by Gabriel Harvey, to the title-page of his copy of John Blagrave, *The Mathematicall Jewell […]* (London, 1585), British Library, C.60.o.7. See Nicholas Popper, 'The English Polydaedali: How Gabriel Harvey Read Late Tudor London', *Journal of the History of Ideas* 66 (2005), 351–81.
[n]Susan M. Maxwell, 'Molyneux, Emery (*d.* 1598)', *Oxford Dictionary of National Biography* <https://doi.org/10.1093/ref:odnb/50911> [accessed 4 September 2018].
[o]Made the instruments described in Thomas Fale, *Horologiographia. The Art of Dialling* […] (London, 1593), sig. A4[v].
[p]Turner, *Elizabethan Instrument Makers*, pp. 29–31.
[q]Thomas Hood, *The Use of the Two Mathematicall Instruments, the Crosse Staffe […] and the Jacobs Staffe*, 2nd edn (London, 1596), sig. A1[r].
[r]Bryden, 'Evidence from Advertising', p. 37, n. 32.
[s]Museum of the History of Science, Oxford, inv. no. 38251.
[t]Turner, *Elizabethan Instrument Makers*, p. 283.
[u]Optical Museum, Ernst Abbe Foundation, Jena, Germany, inv. no. 03/0731; Turner, *Elizabethan Instrument Makers*, pp. 249–50.

themselves at the centre of a movement for reform.[25] The key figures in this respect are Robert Recorde (c.1512–1558), Leonard Digges (c.1515–c.1559) and, later, his son Thomas (c.1546–1595), John Dee (1527–1609), William Bourne (*fl.* 1565–1588), John Blagrave (before 1560–1611), and Thomas Hood (bap. 1556–1620).[26] Each wrote in praise of both the mathematical project and specifically the use of instruments, and their works cover the entire period under discussion. The earlier writers – Recorde, Digges and Dee – had extensive knowledge of developments in practical mathematics on the continent, either through travel, personal connections or wide reading. All enjoyed some degree of patronage from wealthy mathematical enthusiasts,

[25]A specific statement to this effect can be found in Ash, *Power, Knowledge, and Expertise*, 'Introduction'.
[26]For more on these men see their entries in the *Oxford Dictionary of National Biography*, and the capsule biographies in Taylor, *Mathematical Practitioners*.

and had at least passing knowledge of the making and use of instruments. But in each case their precise impact is difficult to judge. The books produced by Recorde and Leonard Digges went through a large number of editions throughout the sixteenth and seventeenth centuries; Dee played an important role in the crafting of Elizabethan state policy, advising on imperial expansion, metallurgy, the use of instruments in navigation and other more esoteric matters; Bourne, Blagrave and Hood enjoyed mixed fortunes, moving between mathematical authorship and other more practical employment.[27] By calling into question their influence on others I do not mean to downplay the achievement of these writers, especially in the area of crafting rhetorical tools for the advancement of their respective disciplines. In the prefaces to their works they justified the use of instruments as a necessary part of modern statecraft, linking the mathematical disciplines together into a coherent whole, with particular tasks (navigation, surveying, gunnery) united by common techniques (trigonometry) and tools (angular measuring devices), in a hierarchy of knowledge, with arithmetic and geometry as its underlying principles and cosmography as its highest achievement.

To give a specific example that is also germane to the present case: the use of mathematics in navigation was little known in England until the middle decades of the sixteenth century.[28] One factor in preventing its more general employment – even as the necessity for voyaging beyond the coastlines of Europe became clear – was the division between pilot and captain that required of the latter no navigational knowledge whatsoever.[29] Here the promotion of practical mathematics by and amongst the gentry was an efficient means of introducing technical proficiency into navigation. Under Elizabeth it became increasingly inappropriate to captain a ship without knowledge of the mathematical and instrumental principles of navigation, and this enabled pilot and captain to work together in planning and executing ever more ambitious voyages.[30] Hence in the work at court of John Dee and the publications of William Bourne we can see a clear role for the self-proclaimed 'Well Wisher to Navigation' in the development of the mathematical arts.[31]

[27]On Recorde see Gareth Roberts and Fenny Smith (eds), *Robert Recorde: The Life and Times of a Tudor Mathematician* (Cardiff: University of Wales Press, 2013); on the Digges senior and junior see Johnston, 'Making Mathematical Practice'; there is an extensive literature on Dee, but for the present purpose I recommend the essays in Stephen Clucas (ed.), *John Dee: Interdisciplinary Studies in English Renaissance Thought* (Dordrecht: Springer, 2006), and Glyn Parry, 'John Dee and the Elizabethan British Empire in Its European Context', *The Historical Journal* 49 (2006), 643–75; on Bourne see E. G. R. Taylor, *Tudor Geography 1485–1583* (London: Methuen & Co., 1930), pp. 153–61; on Blagrave see Taylor, 'A "Practique Discipline"?', and Robert T. Gunther, 'The Uranical Astrolabe and Other Inventions of John Blagrave of Reading', *Archaeologia* 79 (1929), 55–72; on Hood see Johnston, 'Mathematical Practitioners and Instruments', p. 330ff.

[28]See David W. Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times* (London: Hollis and Carter, 1958), pt. I.

[29]E. G. R. Taylor, 'Instructions to a Colonial Surveyor in 1582', *Mariner's Mirror* 37 (1951), 48–62, esp. 48–9.

[30]Waters, *The Art of Navigation*, pt. II.

[31]This phrase is cited in a later usage by Waters, *The Art of* Navigation, p. 468, but was a typical formulation of the late-sixteenth and early seventeenth centuries.

However, to focus too closely on mathematical authorship is to miss the importance of the very instruments Dee, Bourne and their colleagues were advocating. In order to understand this I propose that we draw on the insights of historians and sociologists who have examined other large-scale technological changes in the sciences. For instance, in writing about experimental philosophy in the seventeenth century, Steven Shapin and Simon Schaffer divide Robert Boyle's strategy into three parts:

> a *material technology* embedded in the construction and operation of the air pump; a *literary technology* by means of which the phenomena produced by the pump were made known to those who were not direct witnesses; and a *social technology* that incorporated the conventions experimental philosophers should use in dealing with each other and considering knowledge-claims[32]

In a similar vein, Wiebe Bijker, Thomas Hughes and Trevor Pinch describe three 'layers' to the term 'technology':

> First, there is the level of *physical objects* or *artifacts*, for example, bicycles, lamps, and Bakelite. Second, 'technology' may refer to *activities* or *processes*, such as steel making or molding. Third, 'technology' can refer to what people *know* as well as what they do; an know example is the 'know-how' that goes into designing a bicycle or operating an ultrasound device in the obstetrics clinic.[33]

These two schema can be usefully combined in thinking about the development of practical mathematics as a technological system. With regard to Shapin's and Schaffer's classification, clearly the earlier mathematical programme relied on material technologies – the instruments themselves. It also depended on literary technologies, though these were different in important ways from those employed in experimental cultures. For practical mathematics the key was to establish a doctrine of utility within a framework of gentlemanly learning. The relevant *social technology* is obviously related to this, but has been somewhat contentious.[34] *Who* could vouch for the utility of mathematics and in which arenas is not as well understood as we might like, nor is the issue of the role of expertise in different social settings – but this, at least, has been studied by historians of instruments and does not directly concern me here.[35] As with Shapin and Schaffer, the schematization given by Bijker, Hughes and Pinch gives us a first 'layer' of

[32]Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, NJ: Princeton University Press, 1985), p. 25.

[33]Wiebe E. Bijker, Thomas P. Hughes and Trevor Pinch (eds), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, MA: MIT Press, 1993, first ed. 1987), p. 4.

[34]See in particular the debate raised by Ash, *Power, Knowledge, and Expertise*, which was critically engaged with by Pumfrey, 'Review of Eric H. Ash', amongst others.

[35]A particularly revealing episode in this respect is the priority dispute between William Oughtred and Richard Delamain in the early 1630s, in which many otherwise unspoken conventions and prejudices were articulated in a forceful exchange between the two protagonists. See Hill 'Juglers or Schollers?'; Anthony J. Turner, 'William Oughtred, Richard Delamain and the Horizontal Instrument in Seventeenth Century England', *Annali dell'Istituto e Museo di Storia della Scienza di Firenze* 6 (1981), 99–125; Frances Willmoth, *Sir Jonas Moore: Practical Mathematics and Restoration Science* (Woodbridge: The Boydell Press, 1993), ch. 2.

materials – instruments. Then we have processes – the crafting of instruments through metalwork, turning and engraving, and the means by which instruments and their complex uses were incorporated into the established tasks of navigation, gunnery and surveying. Then there is 'know-how': the skill in making and also using instruments. The point here is that all three layers are intertwined: instruments carry the means to reverse-engineer their uses; instrumental processes were matters of both material fact (supplying instruments to certain other trades) and a rhetorical achievement (as we have seen above); and learning the principles of instruments was often achieved through making them – or at least working through their making on paper.[36] The benefit of thinking (*pace* Shapin and Schaffer) in terms of material, literary and social technologies is that it draws attention to the particular roles and rhetorical moves that were made in order to establish matters of authority and expertise. The benefit of thinking (*pace* Bijker, Hughes and Pinch) in terms of artefacts, processes and know-how is that it draws attention to the material and intellectual conditions necessary for things to happen in the real world. Processes and know-how both depend on the existence of materials, and the latter give meaning to social and literary technologies.

We have now seen that the development of the instrument trade is a tractable historical development, connected in important ways to the guild system and the rhetorical achievement of mathematical writers. Thinking systematically about the nature of technological change leads to my main premise: that the management of materials is key to understanding practical mathematics. In order to account for this, I argue, we need explanations that can in turn account for the transformation in instrument making in the decisive decade of the 1570s. This can be found in a new source: a patent dating from c.1575, granting a monopoly over instrument making and specifically singling out a navigational instrument as the rationale for reforming the trade.

3. New evidence of patenting in Elizabethan England

3.1. Stephen Browne's book

The patent that concerns this paper is held at the Bodleian Library in Oxford, amongst the Rawlinson Papers.[37] Before turning to the text of the patent itself, it is necessary to consider its context, namely 'Rawlinson C404.5', 'A collection of writs, pardons, letters patent, etc., in the time of Q. Eliz.; with a table of

[36]The latter has not been properly understood: instrument manuals supply instructions for making on paper, and often explicitly suggest paper as a medium; many commonplace books exist containing evidence of this kind of working through. Hence we should be cautious in assuming that 'making' meant working with wood or metal, and also in drawing a dividing line between constructing diagrams and making physical instruments.

[37]See W. D. Macray, *Catalogi codicum manuscriptorum Bibliothecæ Bodleianæ partis quintæ fasciculus secundus, viri munificentissimi Ricardi Rawlinson, J.C.D., codicum classem tertiam, in qua libri theologici atque miscellanei, complectens; accedit in uniuscujusque classis codicum contenta index locupletissimus* (Oxford: E Typographeo Clarendoniano, 1878).

the subjects at the end. fol. 159.'[38] This is the last part of a bound volume containing five separate collections of historical and legal information. Prior to the clergyman and antiquary Richard Rawlinson (1690–1755) the volume was in the possession of the lawyer Andrew Philipps (1601–1690). The fifth section, of relevance to the present study, is a separate book containing fair copies of hundreds of writs, pardons, letters patent and so on. At the top of the first leaf, verso, the following is written, in a different hand from the text itself:

> This booke was written by Stephen Browne a clark in the Crowne office in Channcerie who served in that office 36 yeres and gaue it me 3° ~~March~~ Aprill 1604.[39]

This is apparently signed 'G. Coppinger'. While Coppinger has escaped my inquiries, brief biographical details of Stephen Browne are given near the end of the book itself. There Browne records that his parents George Browne and Margaret Gardener were married 29 October 1538, and that he himself was christened 25 Feb 1541.[40] The only other piece of evidence about Browne's life that I have been able to find solves the question of the nature of the book and gives a date range for Browne's career. In the Record of the House of Commons for 1601 we find that Browne was called to give evidence before the House, specifically about the nature of record keeping in the court of Queen Elizabeth.[41] Browne's evidence includes the fact that it was routine practice for clerks to keep their own personal record books, detailing cases that came before them. In the Commons record we also find the same claim that Browne served in the Chancery for 36 years – so we can tentatively work back from 1601 to give an estimated *terminus ad quem* of 1565 for the commencement of Browne's duties in the Chancery.[42] While it remains possible that Browne began in the Chancery earlier than 1565, it matters little as the earliest date we find in his book is 1566, recorded in a rough list of cases near the back of the volume (though it is safe to assume that these are its earliest records, as the main sequence of entries has no dates prior to 1566).[43]

[38]Ibid., p. 187.
[39]Bodleian MS Rawlinson C404.5, f.159v.
[40]Ibid., f.270v.
[41]Simonds D'Ewes (ed.), *The Journals of All the Parliaments During the Reign of Queen Elizabeth, Both of the House of Lords and House of Commons* (London, 1682), p. 683.
[42]On the origins and development of the Court of Chancery see G. R. Elton, *The Tudor Constitution: Documents and Commentary* (Cambridge: Cambridge University Press, 1968), pp. 150–2; W. J. Jones, *The Elizabethan Court of Chancery* (Oxford: Clarendon Press, 1967).
[43]Bodleian MS Rawlinson C404.5, f.274v. It is worth pausing here to consider the more general significance of Stephen Browne's book. My route to the book was via the index to the Rawlinson MSS, which contains the entry 'Mathematica: […] Patent to one A.B. for mathematical instruments; *temp. Eliz*' (Macray, *Catalogi*, p. 813). But elsewhere in Browne's book, as mentioned in Macray's catalogue, we find all manner of pardons, writs, patents and other documents. Some of these have their correlates in more widely known sources, such as the official Chancery records. Some tally with historical fact, as in the license at f.223r to Sir Nicholas Bacon's son Edward 'to goe beyonde the seas', which he is known to have done in 1576 (see *ODNB*). Yet some – for instance the AB patent – appear to have no corresponding record anywhere else. So here we appear to have an almost completely unknown source for the activities of a clerk in the Chancery for 36 years of Elizabeth's reign. The sole reference to Browne's book that I have found is in C. L'Estrange Ewen's *Witch Hunting and Witch Trials: The Indictments for Witchcraft from the Records of 1373 Assizes Held for the Home Circuit AD 1559–1736* (Abingdon: Routledge, 2011, 1st edn 1929), p. 284, which cites a pardon to one Alice

What can we glean from the other entries? The overall impression is that what we are dealing with here is a reference book, used by Browne throughout his career.[44] Indeed as evidenced by the book itself and by Browne's summons to the House of Commons, this was precisely the period in which many branches of government saw a shift from private note-taking to the more modern mode of systematic record-keeping.[45]

The document under present consideration is found on ff.207r–v. For a full transcription see Appendix I. It begins with a formulaic address to Queen Elizabeth and then introduces 'our welbeloued Subiect AB' – these are not initials, however, for although the manuscript contains many names it also contains many instances of 'AB', and 'ABCD'. I will refer to this document, therefore, as the 'AB patent'. This person, 'AB', the text continues

> hath by his industrie[,] greate labor[,] travell and chardges attayned to the skill of makinge of all manner of Maryners staves and Balla steeles being made of wood comonlye called Mathematicall Instruments with theire appurten[au]nces of metall[46]

The first thing to note is the specificity of the patent: it is not granted for 'mathematicall Instruments' in general, but for 'Maryners staves and Balla steeles'. This refers to an instrument more commonly called the 'cross-staff', also known in the period as a 'mariner's staff' or 'balla stella' – a navigational instrument brought to England around 1550 and increasingly important in the midst of Elizabeth's reign. I return to the nature and significance of this instrument in the following section.

Already, however, and even without going into the specifics of the instruments mentioned, we are in uncharted territory.[47] In his comprehensive

S. for bewitching a cow and pigs in Northfleet. It is neither my present purpose – nor is it within my abilities – to deal with the implications of this, but it is my hope that a scholar better versed in the nature of the Chancery will give Browne's book the attention it deserves.

[44]A few other similar examples survive in the State Papers; owing to the provenance and fact that the book is personal to Browne it is unlikely that Rawlinson C404 is a formal record of the Chancery. The only complicating factor is that the volume contains (at least) two hands, one in the neater, more formal Chancery hand and one in mixed-secretary hand; the former records the cases (including the AB patent), while the latter deals with other administrative matters (for example clerks' fees for various jobs). Some of the entries are also signed by Chancery clerk Thomas Powle, perhaps indicating that these were under the latter's charge, and therefore that the book records precedents beyond those available to Browne himself. On the paperwork of the Elizabethan State see Angela Andreani, *The Elizabethan Secretariat and the Signet Office: The Production of State Papers 1590–1596* (New York and Abingdon: Routledge, 2017).

[45]See G. R. Elton, 'The Journals of the Early House of Lords', *English History Review* 352 (1974), 481–512; A. Hawkyard, 'The Journals, the Clerks of the Parliaments and the Under-Clerks 1485–1601', *Parliamentary History* 33 (2014), 389–421.

[46]Bodleian MS Rawlinson C404.5, f.207r.

[47]In the course of researching this paper I located another patent document – this time an application, c.1580, for a patent from a foreigner. The reference is State Papers Vol. CXLVI. The description on sheet containing the letter reads

> The p[ro]position of an Instrument for navigation whereby at all owres of the day and night seeing the sunne or starres one may knowe by land or sea as well the longitude as the latitude whereof the use is never knowen nor founde before.

Owing to uncertainties over the applicant and the nature of the instrument I have omitted discussion of this document from the present essay; images of the document can be seen on State Papers Online, 1509–1714 (Reading: Gale, Cengage Learning), Gale Document Number: MC4304109559.

review of patenting activity relating to early scientific instruments Mario Biagioli found that 'only a handful of instruments were patented in Europe prior to 1600';[48] in England he found only a single patent granted to a mathematical practitioner – to Edward Wright in 1598 – but that was not in fact for an instrument, rather for a device

> commonly used for drawing up water for the daily use of the city of London […] or of any other city or town, for draining and drawing water out of mines, fen grounds, marshes and other waterlogged grounds and for the grinding of corn.[49]

Across Europe Biagioli found only fifteen instrument patents before 1600.[50] Yet, as I have said, the AB patent is dateable to *circa* 1575. Entries in the book are, with only a very few exceptions, in chronological order, and five leaves prior to the patent document is a document dating to the sixteenth year of Elizabeth's reign, i.e. 1574; nine leaves after the patent there is an entry for 1576. The remainder of the patent is more or less formulaic, but certain phrases ought to be noted, as they bear on what follows. First, we learn that 'AB' has 'practised and devised' his instrument making 'withyn our Realme'.[51] Next, the document emphasizes the importance of the cross-staff

> for all manner of parsons as shall trade and traffique in any affayers vpon the seas into forreyne Countries, bothe for the true directinge of theire navigacions as also for avoidinge of many p[er]illous daungers that maye ensue therof[52]

The text continues by making clear that the patent is granted for the protection of 'AB', 'lest some other parson myghte erroniuslie practise and counterfaite the like Instruments'.[53] The term is for the period of AB's 'naturall liefe', and limits the making of the cross-staff to AB 'by him selfe his servantes and suche as he shall appoynte and sett on woorke'. By the end of the patent, however, it becomes clear that while the cross-staff is the *reason* for the grant of the patent, it is not necessarily its only *aim*:

> all other parsons within this o[ur] Realme of Englande our Subiects borne or Straungers from hensforth [are forbidden] to make the like mathematicall Instruments or any other the premiss [sic] duringe the tyme abovesaide nor to sell or vtter the same unles it be by the consent and appoyntment of the saide AB, vpon payne of forfeiture of all and every the same Instruments so by them to be made contrary to the tenor of these our l[et]res patents[54]

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[48]Biagioli, 'From Print to Patents', p. 141. For the Dutch case see Marius Buning, 'Between Imitation and Invention: Inventor Privileges and Technological Progress in the Early Dutch Republic (c. 1585–1625)', *Intellectual History Review* 24 (2014), 415–27.
[49]C. Smith (ed.), *Calendar of Patent Rolls. 40 Elizabeth I (1597–1598): C66/1477–1492* (Surrey: List and Index Society, 2009), p. 11.
[50]Biagioli, 'From Print to Patents', 145.
[51]Bodleian MS Rawlinson C404.5, f.207r.
[52]Ibid.
[53]Ibid., ff.207r–v.
[54]Ibid., emphasis added.

'Or any other': 'AB' has received a patent not just for the cross-staff, but for making all mathematical instruments. I return to the implications of this clause below, after consideration of the cross-staff, and its importance for Elizabethan navigation.

Before moving on, however, one question must be addressed: was the patent in fact granted? It does not appear on the Calendar of the Patent Rolls and is not recorded anywhere else in the State Papers. While this might appear to count against its being granted, we should recall that, on the one hand, the wording is extremely specific and almost certainly not original with Browne's book.[55] Browne was clearly copying a document that he knew would be passed on elsewhere, and he wanted to record its form and content. On the other hand, record-keeping in Chancery in Browne's time was notoriously poor – a fact that may even explain the existence of the book itself.[56] In 1595, for example, the Master of the Rolls, Sir Thomas Edgerton, wrote to the Treasurer William Cecil (Lord Burghley) to complain that 'of late years there hath been a general neglect of enrolling all such commissions which have passed for her Majesty, and of many other things of great importance'.[57] Others who have looked more systematically have found specific examples of legal pronouncements, known from external evidence, that have left no official record.[58] Browne's book – which contains many other documents, some with external evidence, some without – is surely further evidence of the incompleteness of what we know as the State Papers.[59] In light of the discussion below (Section 3.3), the form of Browne's book, what is known about the incompleteness of the Patent Rolls, and the specificity of the wording of the patent, I proceed on the understanding that it was in fact granted.

3.2. The cross-staff

The cross-staff is a relatively simple device that had applications in astronomy, surveying and navigation (Figure 1).[60] The basic construction and working

[55]Nor is the anonymity of the patentee a problem, as this is in evidence elsewhere in the State Papers and the identity of the applicant would not have been of interest to Browne. See, for example, R. Lemon, *Calendar of State Papers, Domestic Series, of the Reigns of Edward VI, Mary, Elizabeth, 1547–1580* (London: Longman, Brown, Green, Longmans, and Roberts, 1856), p. 29: 'An offer made by A.B. touching the decayed haven of Dover … '.

[56]See Jones, *The Elizabethan Court of Chancery*, p. 132ff.

[57]Ibid., p. 133.

[58]G. D. Duncan, 'Monopolies under Elizabeth I, 1558–1585' (unpublished PhD thesis, University of Cambridge, 1976), p. 18:

> were all monopolies granted by letters patent enrolled? This is a difficult question to answer with any certainty. In general it is thought that not all letters were enrolled, since those granted to private persons entered the record for a fee, and while most grantees may have been ready to pay to have their title deeds on the rolls, some were not. According to Professor Elton, enough unenrolled patents survive in various places to raise doubts about the efficiency of the Chancery.

[59]On the nature of the State Papers see Stephen Alford, 'State Papers of Edward VI, Mary I and Elizabeth I: The Archives and the Documents', *State Papers Online, 1509–1714* (Reading: Gale, Cengage Learning).

[60]See Willem F. J. Mörzer Bruyns, *The Cross-Staff: History and Development of a Navigational Instrument* (Amsterdam: Vereeniging Nederlandsch Historisch Scheepvaart Museum, 1994). On the use of the instrument in surveying see John Roche, 'The Cross-Staff as a Surveying Instrument in England 1500–1640', in *English Map-Making 1500–1650,*

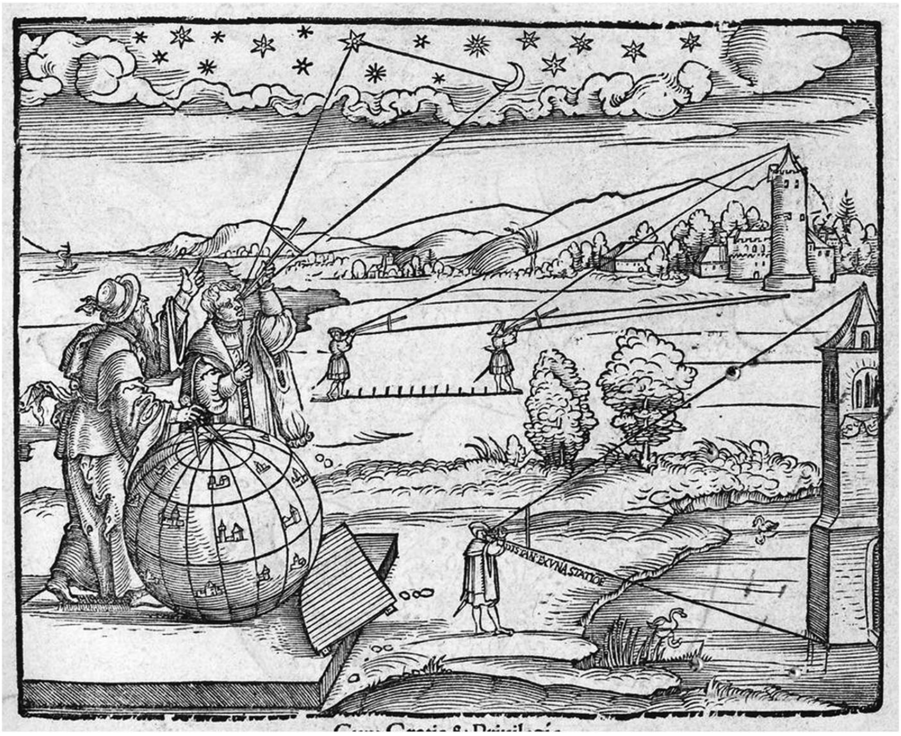

Figure 1. The use of the cross-staff in astronomy and the measurement of buildings. Title-page woodcut from Peter Apian's *Introductio geographica in doctissimas Verneri annotations* (Ingolstadt, 1533). Copyright Alamy.

principles are the same in each case: it consists in a long square-sectioned staff, carrying an unequally divided (tangent) scale, which is traversed by one or more vanes.[61] With the staff held to the eye, the largest vane was moved until its lower edge was seen to touch the horizon and its upper edge the desired object – the latter was usually the pole-star, as this measurement could give a good approximation of the observer's latitude.

The astronomical cross-staff was first described around 1342, and it was introduced to the practice of navigation some time in the 1510s.[62] The expansion of navigation through the fifteenth century had led to the development of the quadrant and the mariner's astrolabe, but it was the cross-staff and its descendants that were to dominate navigation throughout the early-modern period.[63] There are a few sources that show that the cross-staff was in use by English pilots in the 1530s, though it is hard to assess how widely it was

ed. by Sarah Tyacke (London: The British Library, 1983), pp. 107–11; and in astronomy, Roche, 'The Radius Astronomicus in England', *Annals of Science* 38 (1981), 1–32.

[61]By the end of the 1500s two or more vanes were already in employment in order to increase the accuracy of the cross-staff; see Mörzer Bruyns, *The Cross-Staff*, p. 27ff.

[62]Mörzer Bruyns, *The Cross-Staff*, p. 14.

[63]Ibid., p. 13ff.

known.[64] The first substantial description of the navigational cross-staff, complete with instructions and diagrams so that the reader could make their own, was Martin Cortes' *Breve compendio de la sphera y de la arte de navegar* of 1551.[65] The middle of the sixteenth century was a period of intense maritime competition, in particular between England and Spain, and Cortes' text was brought to England by the navigator Stephen Borough and published in 1561, as *The Arte of Navigation*.[66] This text was crucial in the history of English navigation: it was a step on the way to a course of instruction in modern instrumental navigational techniques, and allowed ambitious sailors to undertake a course of self-instruction. It was also indirectly a product of state interest in navigation: the translation was funded by the Muscovy Company, which held a monopoly over trade between England and Russia until late in the seventeenth century.[67] Not only was the cross-staff hardly novel *circa* 1575, then, but it was also specifically available to anyone with basic wood-working skills: in Borough's text the cross-staff is described specifically in terms of its construction, beginning: 'Make a square staffe of yarde of the thyckenesse of a finger, more or lesse accordynge to the goodnesse of the wood.'[68] However, as I explain in more detail in the following section, patents under Lord Burghley did not necessarily have to do with the novelty of a specific invention: rather they were for the advancement of specific trades.

One striking fact about the timing of the AB patent is that it coincides with a text that popularized the cross-staff, that is William Bourne's 1574 *Regiment for the Sea*.[69] This book draws on and claims to go beyond Cortes' *Arte de navegar*, and Bourne also declares his indebtedness to John Dee's famous 'Mathematicall preface' to Billingsley's Euclid (1570).[70] In his own preface Bourne gives the general case for publishing a treatise on navigational instruments:

> it is not unknowne howe necessarie Nauigation is, both for the transportation of our commodities, to find vent for them in other countries […] and also the bringing of other commodities […] And furthermore, for that Navigation, for that Nauigation is the chiefe force and strength of our countrie[71]

[64]See ibid., p. 32; Waters, *The Art of Navigation*, p. 79, n. 1.
[65]Ibid., pp. 75–7.
[66]Full title *The Arte of Navigation, Conteynyng a compendious description of the Sphere, with the makyng of certen Instrumentes and Rules for Nauigations: and exemplified by manye Demonstrations*. Colophon: Imprinted at London: In Powles Church yarde, by Richard Jugge, Printer to the Quenes Maiestie. Subsequent Jugge printings are 1572, 1576, 1579, 1584. The claim that Cortes' text was brought to England by Burrows was made by William Barlow in his *Navigator's Supply* (1597).
[67]Taylor, *The Mathematical Practitioners*, pp. 32–3.
[68]Burrows, *The Arte of Navigation*, Fol.LXXIlv.
[69]Indeed Bourne's text became so associated with the new instruments it describes that it has often been mistakenly cited as the first text to introduce the cross-staff to English readers; that had happened, as mentioned, in 1561.
[70]See E. G. R. Taylor, *Tudor Geography 1485–1583* (London: Methuen & Co., 1930), p. 156.
[71]W. Bourne, *Regiment for the Sea; Conteyning most profitable Rules, Mathematical experiences, and perfect knowledge of Nauigation, for all Coastes and Countreys; most needful and necessary for all seafaryng Men and Travellers, as Pilots, Mariners, Merchants, etc, exactly derived and made by William Bourne*. Colophon: Imprinted at London by Thomas Hacket, and are to be sold at his shop in the Royall Exchaunge, at the Signe of the Greene Dragon [1574].

In the course of his description of a number of instruments, Bourne makes a revealing comment about the universal equinoctial dial, to the effect that he only knows of one person who possesses such an instrument, and that even that person did not understand its use. This makes clear the scarcity of instruments at the time, and the novelty of navigational instruments on board ship.[72] Bourne's description of the cross-staff differs sharply from Borough's: Bourne's text is limited to the use of the instrument, rather than its construction, and the illustration shown is not sufficiently detailed for amateur construction. Clearly this is a text produced in anticipation that its reader could purchase a ready-made instrument.

The next important English source for the cross-staff is not a published book, but a list of instruments purchased by Captain Frobisher's for his first (1576) voyage in search of the North-West passage. These were made by Humphrey Cole, and alongside 'a great globe of metal', sundials, magnetic compasses etc. we find 'an instrument made of wood a stafe named Balestetta [*sic*]', bought for 13s 4d.[73] And in an early account of Frobisher's voyages, the author, George Best, claims that

> instruments of Astronomie to take Longitudes and Latitudes of Countreys, and many other helps, are so commonly knowen to euery Mariner nowadays, that he that hath bin twice at Sea, is ashamed to come home, if he be not able to render accompte of all these particularities[74]

By the end of the sixteenth century the cross-staff was widely used in navigation, and descriptions of its making and use appeared more commonly than before. Aside from new editions of Borough and Bourne, for example, we find just such an account in Thomas Hood's 1596 *The Use of the Two Mathematicall Instruments*. The title-page of this book carries a note that 'The Staues are to be sold in Marke lane, at the house of Francis Cooke', though Cooke was not an instrument maker and can only have been an intermediary.[75] Around this time Thomas Blundeville wrote that the cross-staff was 'commonly used in these dayes'.[76] And, following Hood's text, there were a number of works that feature the cross-staff: William Barlow's *Navigator's Supply* (1597), which concludes with the following couplet: 'Let Staffe, Carde, Compasse, Ship, and Skill, / Depend upon Gods blessed will', and Edward Wright's *Certaine Errors in Navigation* (1599), which dedicates a chapter to the specific difficulties of observing with the cross-staff (mainly having to do with the problem of placing the staff correctly against the eye, and correcting for the height of the observer above the water[77]).

[72]Taylor, *Tudor Geography*, p. 158.
[73]See R. T. Gunther, 'The Great Astrolabe and Other Scientific Instruments of Humphrey Cole', *Archaeologia* 76 (1927), 273–317, quotation 315.
[74]Quoted in Waters, *The Art of Navigation*, p. 146.
[75]Bryden, 'Evidence from Advertising', p. 307
[76]Quoted in Mörzer Bruyns, *The Cross-Staff*, p. 32.
[77]See Gerald Forty, 'Sources of Latitude Error in English Sixteenth Century Navigation', *Journal of Navigation* 36 (1983), 388–403.

From this brief survey of the early use of the navigator's cross-staff we can see a number of relevant trends in sixteenth-century instrument making: the range of individuals involved in promoting instruments, which goes far beyond just the small community of artisans who could make them; the different kinds of texts involved, including translations of navigational epitomes, short didactic texts on specific instruments, and general guides to subjects that could be augmented by instruments – the majority of these written in English.

While it remains difficult to say exactly how extensive was the use of the cross-staff in the sixteenth century, we can certainly mark four key moments in the story of its English adoption: its piecemeal adoption in the 1530s and 1540s; the publication of Cortes' *Arte de navegar* in 1551 and its translation in 1561; Bourne's *Regiment for the Sea* of 1574, alongside the listing for Frobisher's 1576 voyage and the present c.1575 patent document; Hood's 1596 description and advertisement, Blundeville's claim that it was 'commonly used', and the subsequent texts that established the cross-staff as a standard part of the repertoire of practical mathematics, and navigation in particular.

3.3. Patenting instruments

By the time of the AB patent, then, the cross-staff was already well known, and could even be made by an interested amateur from the instructions in Cortes' text. This, however, does not preclude the granting of a patent. Unlike modern patents which are granted for specific and well-defined inventions, early-modern patents offered more general protection for the establishment of a trade.[78] To be more precise: the Elizabethan era saw a shift from an older system by which the Crown encouraged entire industries, to a model whereby specific monopolies were granted to individuals.[79] This was the precursor to the controversies over monopolies in the early Stuart era: abuses of the monopoly system were notorious in the later years of Elizabeth's reign.[80] However, the period 1558–c.1580 has been identified as one in which monopoly patents were successfully introduced as a coherent state policy for any or all of the following motives: to reduce unemployment; to secure supplies and increased quality of important commodities; to strengthen national defences; to increase the numbers of skilled workers; to establish a thriving export market.[81]

As noted, the AB patent permits its licensee 'to make the like mathematicall Instruments or any other', with the additional clause that only 'him selfe his

[78]Biagioli, 'From Print to Patents', p. 150.

[79]Duncan, 'Monopolies Under Elizabeth I', p. 12: 'It does seem clear that letters patent granting monopolies were only issued in any number after the accession to power of Elizabeth and William Cecil – the steady stream of patents in the 1560s was definitely a new phenomenon.'

[80]See E. Wyndham Hulme, 'The History of the Patent System Under the Prerogative and at Common Law', *The Law Quarterly Review* 12 (1896), 141–54, and 'The History of the Patent System Under the Prerogative and at Common Law: A Sequel', *The Law Quarterly Review* 16 (1900), 44–56.

[81]William Hyde Price, *The English Patents of Monopoly* (Boston, MA, and New York: Houghton, Mifflin and Company, 1906), pp. vii–viii. See also Duncan, 'Monopolies under Elizabeth I'; Thirsk, *Economic Policy and Projects*.

servantes and suche as he shall appoynte and sett on woorke' are legally entitled to make instruments. Here there is an implication of something that is explicit in many other patents and was generally known as the reason for the granting of monopolies: the holder of a patent was either encouraged or legally required to train native craftsmen in his trade or 'mystery'. The cross-staff was considered important enough that its making was to be guaranteed by the granting of the patent; but it was also the means by which Burghley could encourage the instrument trade to take hold in England. As Christine MacLeod writes:

> Acquisition of superior Continental technology was the predominant motive for the issue of patents under the guidance of Elizabeth I's chief minister, William Cecil, later Lord Burghley.[82]

Given Burghley's role in the development of the patent system under Elizabeth, it is worth recalling his interest in practical mathematics: his library is known to have contained mathematical works; through his close involvement with the patent system he learned of new inventions and the adaptation of old instruments to new purposes; his intellectual interests had a strongly practical bent; he was a student of the mathematical enthusiast John Cheke and close acquaintance of the translator of Euclid Henry Billingsley; and he was a frequent dedicatee of practical mathematics texts.[83]

Within the context of the advancement of practical mathematics it makes sense that Burghley would support – and perhaps even play a role in commissioning – a patent for the making of mathematical instruments. But to whom was the patent granted? The crucial piece of internal evidence in the text of the patent is the following claim:

> AB hathe by his industrie greate labor travell and chardges attayned to the skill of makinge of all manner of Maryners staves and Balla steeles being made of wood commonlye called mathematicall Instruments withe theyre appurten[au]nces of metall to the belonginge by him practised and devised withyn our Realme, And for that we understande also the saide A to be very expert therein, and one whiche seeketh daylie more and more to p[er]sever in his saide experience[84]

We are looking for an artisan who, *circa* 1575, has been making mathematical instruments – specifically the cross-staff – to a high degree of competence, in England, such that Burghley would seek to reward his endeavour. From the table above we can see that the pioneering instrument maker Thomas Gemini had died in 1562. Following this, the candidates are Robert Norman,

[82] Christine MacLeod, *Inventing the Industrial Revolution: The English Patent System, 1660–1800* (Cambridge: Cambridge University Press, 1988), p. 11.

[83] See B. W. Beckingsale, *Burghley: Tudor Statesman, 1520–1598* (London: Palgrave Macmillan, 1967), p. 257ff. On Burghley as a patron of projects see Felicity Heal and Clive Holmes, 'The Economic Patronage of William Cecil', in *Patronage, Culture and Power: The Early Cecils 1558–1612*, ed. by Pauline Croft (New Haven, CT: Yale University Press, 2002), pp. 199–229.

[84] Bodleian MS Rawlinson C404.5, f.207r.

Bartholomew Newsam, and Humphrey Cole.[85] Norman and Newsam can be discounted on the grounds that their expertise was not specifically in mathematical instrumentation. Our attention must turn to Cole, whose earliest surviving dated instrument is from 1568. The next surviving signed and dated instrument made in England by someone other than Cole dates from 1585 – a sundial made by Augustine Ryther.[86] That gap is reduced, but only slightly, if we turn to textual evidence. For example, there is an advertisement in Edward Worsop's *A Discoverie of Sundrie Errours* (1582), which names Cole and John Bull as working in metal, with John Read, James Lockerson and John Reynolds offering instruments in wood.[87] And Gabriel Harvey boastfully annotated the title-page of his copy of John Blagrave's *Mathematical Jewel* (1585) with a list of makers including 'old Humfrie Cole' and five others.[88] Around this time we begin to see instrument makers appearing in the surviving records of the London guilds, beginning with Ryther at the Grocers' Company.[89] Even if we assume that the makers mentioned by Worsop had been working for a number of years before his advertisement, we find that the AB patent falls directly in the middle of a gap in evidence for the development for the trade, that is, the 1570s.

This is sufficient, I believe, to identify Humphrey Cole as the patentee. We might accept the first claim to expertise ('attayned to the skill of makinge'), as formulaic, but the second ('we understande also the saide A to be very expert therein'), in combination with the further clauses offering protection for AB, strongly suggests that one of the motives of the patent was to reward the patentee for reaching a certain level of technical ability – this being one of the five main motives for patenting mentioned above. This makes sense in light of the fact that Cole was closely associated with Burghley himself. While it may be too much to describe him as Burghley's 'protégé' – as Burghley's biographer does[90] – Cole is known to have been given his first employment in London, at the Royal Mint, by Burghley, and to have been employed separately by the latter in the ill-fated Society of the New Art (a corporation set up to explore the possibility of transmuting lead into copper).[91] Around the time of the patent Cole was also involved with the notorious Frobisher voyages in search of the Northwest Passage, acting, as we have seen, as instrument maker to Frobisher and metallurgist when the latter returned with ore thought to contain large amounts of gold and silver.[92] This takes us to Cole's 'skill of makinge' nagivation instruments specifically. In addition to the cross-staff and other instruments supplied to Frobisher,

[85]Ibid., pp. 111 (Gemini), 61 (Cole). Clifton (p. 285) records a Nicholas Vallin as working from 1565, but although he made an astronomical clock he was not necessarily therefore a maker of 'mathematical instruments'.
[86]Museum of the History of Science (Oxford), inv. no. 13314. Cole's earliest is the 1568 dial made for Richard Jugge; see Turner, *Elizabethan Instrument Makers*, cat. no. 8.
[87]See Clifton, *Directory of British Scientific Instrument Makers*, pp. 228 (Read), 171 (Lockerson), 230 (Reynolds).
[88]See Bryden, 'Evidence from advertising', p. 305.
[89]Brown, *Mathematical Instrument-Makers*, pp. 58–60.
[90]Beckingsale, *Burghley*, p. 259.
[91]See Ackermann, *Humphrey Cole*, for these and other aspects of Cole's career.
[92]Gunther, 'The Great Astrolabe and Other Scientific Instruments of Humphrey Cole', pp. 315–6.

Cole was connected to William Bourne, who in 1578 listed him as the 'devisor' of 'an engine to know the way or going of a Ship, for to knowe [*sic*] how fast or softly that any Ship goeth'.[93]

Returning to the patent itself, recall that it was not limited to the development and marketing of the cross-staff alone; rather it would have granted a monopoly over instrument making in general. The wording is clear: 'all other parsons within this Realme of Englande' are forbidden from making 'the like mathematicall Instruments or any other […] nor to sell or vtter the same unles it be by the consent and appoyntment of the saide AB'.[94] Not only was Cole apparently working on his own through these years, he was working at an exceptionally high level. His instruments are superb, and show evidence of a selective market.[95] These are not the fumblings of an artisan plying a novel trade; these are the results of a mature practice, albeit a lonely one.[96] It is my argument that this was achieved by design – specifically that of Burghley's protective state. Finally, the 'consent and appoyntment of the saide AB' should be understood in two senses: as a limitation on other traders, and an instruction to AB himself. The granting of monopolies was intended to foster trade via succession and training.[97] If the AB patent was granted, and if it was granted to Cole, this would in no way be at odds with the rapid development of the trade by others in the 1580s. In light of the evidence presented here I think it highly likely that the generation of the 1580s – including Augustin Ryther, James Lockerson, John Bull, John Reynolds, Christopher Paine, James Kynvyn and John Read – were directly connected to Cole, either through direct training or licensing.[98] The trade in mathematical instruments in England began with Cole, not just in terms of the quality, range and number of instruments that he made, but in his state-sponsored encouragement of other craftsmen.

4. Conclusion

If the central place of Cole – granted a monopoly patent under Burghley's supervision in the 1570s – is accepted, the picture of the development of practical mathematics as both a state interest and commercial venture becomes much clearer. As noted, the rapid growth of the trade in the 1580s and 1590s is explained. The guilds are now not required to have encouraged the trade, only

[93]William Bourne, *Inuentions or Deuises. Very necessary for all Generalles and Captaines, or Leaders of men, as wel by Sea as by Land* (London, 1578), pp. 15–17.
[94]Bodleian MS Rawlinson C404.5, f.207v.
[95]Turner, *Elizabethan Instrument Makers*, pp. 23–5.
[96]On Cole's skill see Turner, *Elizabethan Instrument Makers*, pp. 20–5.
[97]MacLeod, *Inventing the Industrial Revolution*, p. 12.
[98]The few surviving instruments we have from these makers (in particular Ryther and Kynvyn) have already led others to speculate that they were related to Cole in some way, though no documentary evidence of this has been found. For Ryther and Cole see Laurence Worms, 'The London Map Trade to 1640', in *The History of Cartography, Volume 3: Cartography in the European Renaissance*, ed. by David Woodward (Chicago, IL: University of Chicago Press, 2007), vol. II, pp. 1693–721, p. 1703; for Kynvyn and Cole see Taylor, *The Mathematical Practitioners*, p. 172.

to have accommodated it. The evidence of surviving materials – a wide range of instruments made by Cole, suddenly, after 1568, and very few by any others – makes more sense. And the contested role of 'mathematical practitioners' or 'expert mediators' can be better understood. Burghley certainly had an interest in such people – as attested by his friendship with Billingsley, his acquaintance with Dee and his literary citation by Worsop, Blagrave and Digges. Yet he had direct access to Cole, and could engage or encourage him as he wished, without any intermediary. Specifically, Burghley could employ Cole as a metallurgist, enjoin him to go prospecting, and grant him a monopoly over instrument making. The latter was not simply a sign of friendship or kindness, rather it was a means of developing a strategically important trade in England and thus diminishing the need for the import of skilled labour or specific technologies. Mathematical publishing and 'expert mediation' still had their places in the total system of practical mathematics, but the use of instruments in specific contexts on any kind of scale required makers who could expect to profit from their work. This is what Burghley granted Cole.

Above I mentioned the close relationship that existed between instrument making and publishing. The pattern that emerged may seem surprising: practitioners of higher social standing such as Leonard Digges, John Blagrave and Thomas Hood wrote texts that often described not only the use but also the making of instruments for navigation, astronomy, surveying, gunnery and the making of sundials. Secrecy seems not to have been valued: inventions were described in full, often down to the tools that would be required to make instruments from scratch. This situation seems to have worked to the advantage of both writers and artisans, presumably because materials and skills were in short supply: as the adverts suggested, readers unable to make their own instruments were instructed to travel to one of the London shops to purchase instruments (almost certainly on commission rather than ready made).[99] As Biagioli has observed, it may have been considered generally beneficial for enthusiasm for practical mathematics to be stoked up by this 'open source' style of publishing inventions.[100] But there may also be more to this story than meets the eye, as the case of the AB patent shows. As with the pattern of surviving instruments, we might also break down the second half of the sixteenth century into more discrete units: the question of when exactly texts began to describe instruments in enough detail for them to be made by amateurs could usefully be explored.

These specific conclusions lead to broader reflection on the nature of practical mathematics in this period. I have argued here that we need to understand

[99]Of course, texts from this (as indeed any other) era are full of careful rhetoric, and it is not clear either how practicable amateur making was or how the possession of texts related to the purchase of instruments. Were instrument books 'manuals' for already-purchased instruments? The presence of adverts suggests this may not have been the intention. But did readers really want to wander across fields with a theodolite in hand when they could (as it were) travel across and measure them in their minds, through diagrams and in complex calculations?

[100]Biagioli, 'From Print to Patents', p. 166. See also Pamela O. Long, 'The Openness of Knowledge: An Ideal and Its Context in 16th-century Writings on Mining and Metallurgy', *Technology and Culture* 32 (1991), 318–55.

practical mathematics as a matter of state interest as well as personal capability. This is essential because of the foundational role that the mathematical arts play in explanations of later developments. At least for the English case, it is economic policy, the legal apparatus of statecraft, and deployment of instruments within the early-modern commodity market that underpin the development of universally applicable, technologically mediated forms of expertise.

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Appendix. Full text of Bodleian MS Rawlinson C404.5, f.274v-r (c. 1575)

Elizabeth by the grace of God etc. To all men to whome these presente shall come to greatinge. Whereas wee understande and are crediblie enformed that our welbeloued Subiect AB hathe by his industrie greate labor travell and chardges attayned to the skill of makinge of all manner of Maryners staves and Balla steeles being made of wood comonlye called mathematicall Instruments withe theyre appurten[au]nces of metall to them belonginge by him practised and devised withyn our Realme, And for that we understande also the saide A to be very expert therein, and one whiche seeketh daylie more and more to p[er]sever in his saide experience, Wee therefore myndinge the advauncement ~~and~~ of all suche our louinge Subiects as doe desier to be well seene in the arte whiche theie professe, And consideringe also howe necessarie and notorious a thinge the knowledge of p[er]fect makinge of the saide saide [*sic*] mathematicall Instruments <is> for all manner of parsons as shall trade and traffique in any affayers vpon the seas into forreyne Countries, bothe for the true directinge of theire navigacions as also for avoidinge of many p[er]illous daungers that maye ensue therof, And for that saide AB doubtinge lest some other parson myghte erroniuslie practise and counterfaite the like Instruments not onlye to the greate hynderaunce and discouragement of the same A after his [f.274r] saide greate labor and travaill therein susteyned, but also be an occasion of moste manifest errors for the state and sure conductinge of navigacions as is alreadie partelie experymented and sene. Knowe ye therefore that we consideringe also the premisses and myndinge to avoide suche erro<r>s of our grate esp[ec]iall certen science and mere mocyon at the humble suyte of the saide AB are pleased and contented and by these presente for vs our heiers and Successors doe give and graunte lycence full power lib[er]tie and aucthoritie vnto the saide AB that he by him selfe his servantes and suche as he shall appoynte and sett on woorke shall have thonlie makinge of all and all manner the said Maryners staves and Balla steeles made of wood comonlie called mathematicall Instruments withe theire appurten[au]nces of Mettall to them belonginge And the same Instruments so made to vtter and sell to his moste p[ro]fitt and aduauntage, and as he can best agree w[ith] the Byers, And the saide AB the only woorkeman and maker of the said mathematicall Instruments wee doe by these presents [*sic*] for vs our heiers and Successors constitute ordeyne name and appoynte. To haue holde and enioye the onlie makinge of all and all manner the saide Maryners Staves and Balla Steeles made of wood comonlye called mathematicall Instruments withe theire appurtenInces of Mettall to them belonginge withe all other the premisses in manner and forme above sp[ec]ified, to the saide AB duringe his naturall liefe Forbidding and proh[ib]itinge all other parsons within this o[ur] Realme of Englande our Subiects borne or Straungers from hensforth to make the like mathematicall Instruments or any other the premiss duringe the tyme abovesaide nor to sell or vtter the same unles it be by the consent and appoyntement of the saide AB, vpon payne of forfeiture of all and every the same Instruments so by them to be made contrary to the tenor of these our l[et]res patents, and as theie will farder aunswere to the contrarye at theire vttermost perrills. Any statute lawe proclamacion or restraynte to the contrarye hereof heretofore made ordeyned or provided notwithstandinge. Willing chardging and commaundinge all and singuler our Officers Ministers and Subiects not only to suffer and p[er]mytt the said AB quiethe to enioye all and singuler the premisses accordinge to the tenor and meaninge of our said l[et]res patents without any manner theire lett trooble interrupcyon or contradiccyon, but also to be aidinge helpinge and assistinge the saide AB in the due execution hereof, As ye and eu[er]y of the[m] tender our pleasure and will aunswere to the contrarye at their vttermmost perrills. In witness whereof we haue caused etc.