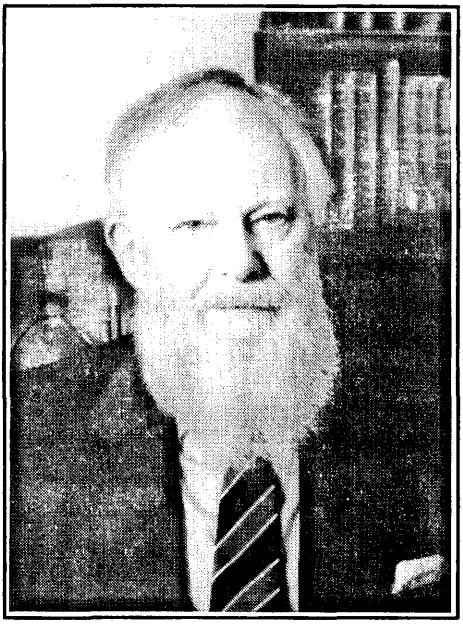

THE INSTRUMENT MAKERS OF ELIZABETHAN ENGLAND

G.L'E. Turner

The need to measure land developed as soon as communities became settled. The Flemish "landmeeter" — a word that still means surveyor — was in existence as early as the twelfth century, for in 1190 this description was added to the name of a practitioner : Bernoldo Landmetra. In 1282, Johannes Landmetere is referred to as Geometricus and Agrimensor. During the first half of the sixteenth century the scene was being set for the development of surveying into a profession, requiring increasing skill and accuracy, and also the use of instruments devised to make angular measurements. Surveying was to become a science alongside, and to a certain extent as a result of, the development of deep-sea navigation and the growing military skills of fortification and siege associated with the use of artillery. The accurate determination of position, both at sea and on land, became of increasing economic importance as ships left the security of coastal waters, and as new tracts of unexplored territory were discovered. One of the major activities of a surveyor is levelling. Water running from high ground to sea level causes problems in flat coastal area as in the Low Countries and the English Fens. It was the surveyor's task to devise waterways, dikes, and locks to rescue land for agriculture and hence economic gain.

The disintegration of the medieval pattern of land tenure led to the establishment of a much higher proportion of individual ownership, and so to the need for more accurate definitions of boundaries. As a result of these needs the art of map-making grew rapidly in importance at a time when the necessary skills of engraving and printing were available, and most notably in the Low Countries. The engraver of copper-plate illustrations could also divide the circle on brass instruments for the use of the surveyor and the seaman. Another important requirement, both for

instrument makers and for those who practised surveying and navigation, was mathematical knowledge. As with printing and engraving, mathematics, in particular in the practical applications, was developed on the Continent of Europe by such notable scholars as Martin Waldseemüller (1470-*c.*1518) in Lorraine, and Gemma Frisius (1508-1555) at Louvain. During the mid-sixteenth century, John Dee (1527-1608), a founder Fellow of Trinity College, Cambridge, spent three years studying in Paris, Brussels, and Louvain, and on his return home he pioneered the provision of textbooks and translations of Continental practice in English. At much the same time, in 1543, the highly influential work by Robert Recorde, *The Ground of Artes Teaching the Worke and practise of Arithmetike* was published, which, running through twenty-eight editions in the next 150 years, introduced pen reckoning and the use of arabic numerals to a wide public. Before the new, angular measuring techniques could be satisfactorily imported from the Continent, a prior requirement was a knowledge of arithmetic : arabic had to replace roman numerals. In the Exchequer Records arabic numerals were first used at the end of the sixteenth century, but roman did not disappear for another 60 years. Accounts were done by using ruled boards or cloths, and casting-counters : hence the phrase — to cast one's accounts. Recorde may be regarded as the founder of English mathematics, since his text-books opened the way for self-education for the new class of technicians. He was also the founder of the English school of mathematical practitioners, among whom were later numbered many of the great London instrument makers.

The English mechanician, Cyprian Lucar (fl.1564-1590), who was educated at Winchester College and New College, Oxford, published at London in 1590 his *Treatise named Lucar Solace*, where he illustrated the instruments in common use during the late sixteenth century. His selection is soon confirmed by John Norden in *The Surveyors Dialogue* of 1607. The illustration in Lucar's book shows a plane table with frame to hold the paper and an alidade or ruler, a chain, a square, and a pair of compasses. Rods and cords for direct measurement were in use throughout the century, but the chain, an obvious — though expensive — improvement on the cord because it was not subject to variation in length, was first referred to by Conrad von Ulm in a book he published

at Strasbourg in 1579. The length of the chain was related to various local measures, and the Gresham Professor, Edmund Gunter proposed a decimal chain of 100 links in 1620. Also used for direct measurement of length, though not shown by Lucar, was the waywiser. A dial recorded the revolution of the wheels of a carriage, and soon a hand-propelled measuring wheel, also called a waywiser or a perambulator, came into use in the seventeenth century, and continues to be used today.

The plane table was the most ubiquitous of sixteenth-century surveying instruments, being practical and easy to use in the field. It is a board with paper held down on it, and an alidade or ruler with sights at each end. By aligning the sights with topographical features and marking the line of view by pencil along the side of the alidade, the plan is simply made. The plane table was, however, despised by those with mathematical knowledge. Thomas Digges, in the 1591 edition of his father's book, *Pantometra,* described it as "an Instrument onely for the ignorante and unlearned, that haue no knowledge of Noumbers". Throughout the sixteenth century mathematicians were working on versions of an instrument for surveying that eventually became the theodolite. The first man to design what was recognizably an altazimuth theodolite was Martin Waldseemüller, who produced in Lorraine not only world maps, but also detailed maps of his own area of the upper Rhine. In the 1512 edition of the *Margarita Philosophica* of Gregor Reisch, which is a philosophical and scientific compendium, was included a section on architecture and perspective by Waldseemüller that depicted an instrument called the 'Polimetrum', which contained the two essential devices for the simultaneous measurement of horizontal and vertical angles.

Leonard Digges (d.1571) of University College, Oxford, and his son, Thomas (d.1595) of Queens' College, Cambridge, were the authors of two influential texts on mathematical surveying, published in the second half of the sixteenth century. In the first of these, entitled *Tectonicon,* and published at London in 1556, Leonard described those for whom the book was intended as 'Surveyors, Landmeaters, Ioyners, Carpenters and Masons'. As well as providing tables to help those who

used measuring cords, he recommends three instruments : the carpenter's ruler, the carpenter's square, and a version of the cross-staff. It was, however, in his posthumously published *A Geometrical Practice Named Pantometria* (1571), completed by his son, that Digges introduced instruments for the specialist surveyor. He described three instruments that could be combined to form what he called a 'topographicall instrument'. These were a vertical quadrant with shadow square that was intended to measure heights; a square with inscribed quadrant and alidade, mounted on a staff; and a circular plate divided into degrees with a centrally mounted alidade, to which Digges gave the name 'theodelitus'. The combination was, in effect, an altazimuth theodolite, while the 'theodolitus' by itself was the simple theodolite. An astrolabe could be used for measuring horizontal or vertical angles, and one can see that the theodolite, which combines together the means to make both measurements, can be said to derive from the astrolabe. And sixteenth-century astrolabes often incorporate a magnetic compass. Aaron Rathborne, in his book called *The Surveyor*, published in 1616, lists the following instruments : the plane table; the altazimuth theodolite; the circumferentor; the simple theodolite; and a chain. This list reflects the gradual acceptance during the course of the sixteenth century of versions of the more elaborate mathematical instruments that had at first been regarded as too complex by the working surveyor.

Much the same pattern of development is apparent with instrumentation for navigation at sea. While in coastal waters, the seaman relied on experience, a lead line, and a magnetic compass. Crossing the Atlantic was a completely different matter, for experience was very hardly gained, and instruments were an essential requirement when out of sight of land, birds, and other tell-tale features. He still needed the lead, log-line, and magnetic compass, but also a quadrant, a forestaff, a sand-glass, charts, and a good knowledge of the star map. Two books on navigational techniques from the end of the Elizabethan period deserve special mention. One is William Barlow's *The Navigators Supply* of 1597. Barlow (fl. 1564-1625) was a graduate of Balliol College, Oxford, churchman at Winchester and then chaplain to Prince Henry, son of James I. Although Barlow abhorred the sea, by knowing his mathematics,

and talking with seamen, he learnt of what was needed and proceeded to invent instruments. He improved the magnetic compass, and invented or improved the variation compass, *Traveller's Jewel,* pantometer, the nautical hemisphere, and the traverse board. There was an advertisement on his title page, just above the engraving of the *Traveller's Jewel* which ran :

> If any man desire more ample instruction concerning the vse of these instruments, hee may repayre vnto Iohn Goodwin dwellinge in Bucklersburye teacher of the grownds of these artes. The instruments are made by Charles Whitwell, over agaynste Essex howse, maker of all sortes of mathematicall instruments, and the graver of these portraytures [that is to say, the engravings in the book].

David Waters, in his masterly history of navigation, has written of Edward Wright : "his book set the seal on the supremacy of the English in the theory and practice of the art of navigation at the end of the sixteenth century". Like Barlow, a Cambridge mathematician, Wright (1558-1615) was brought into the Queen's service as a result of the Armada, and travelled on naval ships to gain practical experience. The result was *Certaine Errors in Navigation, arising either of the ordinarie erroneous making or using of the sea Chart, Compasses, Crosse staffe, and Table of declination of the Sunne, and fixed Starres detected and corrected,* published in 1599. Here Wright provided a most thorough mathematical treatment of errors in measurements and in the practices of seamen.

Printers and copper-plate engravers were craftsmen from the Continent who were to influence English practice. Robert Recorde's *The Ground of Artes* was printed by Reynor Wolfe, who left his native Drenthe in the north of the Netherlands to settle in London in 1533. Even fifty years later it was difficult to find an English printer who could set up a mathematical work correctly. Throughout the sixteenth century the English were indebted to the Continent, and especially to Flanders, for the skills of printing, of engraving book illustrations, maps, and

instruments, and for surveying techniques. All these activities are melded together in the work of Christopher Saxton (d.1596), who was obliged to farm out his engraving needs to several men to hasten the production of engraved maps. His *An Atlas of England and Wales*, published at London in 1579, contains 34 maps, 23 of them bearing the engraver's name. There are seven different signatures, four of them by Flemings, and three by Englishman. The English are : Augustine Ryther (4 maps), Francis Scatter (2), and Nicholas Reynolds (1). Ryther was to become a leading instrument maker. The migration of skilled men increased during mid-century when the grip of Spanish religious persecution was tightening on the Netherlands, finally to result in the Revolt which broke out in 1564.

The main materials used for making mathematical instruments were brass and wood, usually boxwood. Prior to the sixteenth century, brass that was needed for such uses as candlesticks, or memorials in churches, had been imported from the Continent, and was expensive. Now with the military threat from Catholic Europe and growing demand for brass and bronze, the Royal Charters for the Company of Mineral and Battery Works and the Company of Mines Royal for the production of brass and brass plate amongst other things, were granted in May 1568, thus allowing English manufacture for the first time. Humfrey Cole, of whom more will be said later, was closely involved in the setting up of the Mineral and Battery Works, which necessitated bringing in German craftsmen to train Englishmen in metal-working skills, and in prospecting for ores. Cole was engraver of dies for the Royal Mint, as well as the leading instrument-maker of the period.

Type of Instruments Made

Compendia & pocket dials	25
Surveying instruments	18
Horizontal dials	12
Drawing instruments	10
Astrolabes	9

Navigation instruments	7
Quadrants	7
Gunnery instruments	4
Nocturnals	4
Armillary spheres	2

The great influence on instrument design, map, chart and globe making came from Gemma Frisius and Gerard Mercator, and it was from this Louvain area that came the man who can be regarded as the first to establish the scientific instrument-making trade in England. Thomas Gemini (*c.*1510-1562) came from a village near Liège, and it is probable that he served his apprenticeship alongside Mercator. He moved to England, and at Blackfriars in London, he carried on the business of map-engraver and mathematical instrument-maker. He made his reputation with his plates for his own printing of the *Anatomy* of Vesalius, issued in 1545. This earned him an annuity of £10 from King Henry VIII. An astrolabe by him is in the Musées Royaux d'Art et d'Histoire, Brussels, bearing the arms of the Duke of Northumberland and of King Edward VI. It is dated 1552. In 1555, Gemini printed the *Prognostications* of Leonard Digges, and in the following year, Digges' *A Boke Named Tectonicon.* It was said there that the instruments could be obtained from Gemini. Another astrolabe was made for Queen Elizabeth I. This is dated 1559, is engraved with the queen's name and the royal arms, and is in the Museum of the History of Science, Oxford.

There is no doubt that Humfrey Cole (*c.*1530-1591) was London's foremost mathematical instrument maker of the sixteenth century. Cole was from the North of England, and was employed at the Royal Mint. He undertook to supply all the instruments described in the 1571 edition of Digges' *Pantometria.* Cole's masterpiece must surely be the large, two-foot diameter astrolabe, dated 1575, in the possession of the University of St Andrews, Scotland. This has several resemblances to the Gemini astrolabe made for Elizabeth I, both instruments having on the back a horizontal projection of the sphere derived from the planisphere of Gemma Frisius. Cole's production is both varied and extensive, judging by the twenty-six known instruments, and two engravings. It is clear,

also, that he had an influence on subsequent makers, as would be expected. This is shown by comparing Cole's two theodolites with those by Ryther and James Kynvyn. One must also compare the pocket dials by Cole, Ryther, Kynvyn, Whitwell, and Elias Allen. Although Cole was free of the Goldsmiths' Company and not the Grocers' Company, Cole may be said to be the originator of that line of craftsmen. Kynvyn was a younger contemporary of Cole, and is mentioned with him by at least one customer. The Cambridge scholar, Gabriel Harvey (*c.*1550-1630), in a note on his copy of Blagrave's *The Mathematical Jewel*, wrote : "James Kynvyn of London, near Powles [St Paul's]. A fine workman & mie kinde frend : first commended vnto me bie M.Digges & M.Blagrave himself... He & old Humfrie Cole, mie mathematical mechanicians."

Instruments by Humfrey Cole

1568	HVMFRAY COOLE	compendium
1569*	Humfray Coolle	gunner's compasses
1569	Humfray Colle	compendium
1570*	*not signed*	6-in jointed rule
1571*	H. Cole	nocturnal
1574	Humfrey Cole	sundial, quadrant
1574	Humfray Colle	sundial, quadrant
1574	Humfrey Côle	12-in surveyor's rule
1574	Humfrey Côle	12-in surveyor's rule
1574	Humfrey Cole	astrolabe
1574	H. Cole	theodolite
1575	H. Cole	gunner's compasses
1575	Humfrey Côle	12-in surveyor's rule
1575	Humfrey Côle	12-in surveyor's rule
1575	H. Cole	sundial, poke
1575	Humfrey Cole	compendium
1575	Humfrey Cole	compendium
1575	Humfridus Côle	astrolabe
1579	H. Cole	sundial, horizontal
1579	Humfrey Côle	compendium

1579	Humfrey Côle	compendium
1582	H. Côle	plane-table alidade
1582	Humfrae Colle	sundial, horizontal
1582	Humphrey Cole	armillary
1586	H. Cole	theodolite
1590	Humfrey Cole	compendium

* = not dated. Note the variations in the way Cole spelled his name.

A key factor in the establishment of the instrument-making trade was the way in which it could become grafted on to the existing guild structure. The City of London Guilds were medieval and, by the 16th century, what are known as the Twelve Great Livery Companies had emerged as leaders. To learn a craft and to practise it meant that an apprenticeship had to be served, and the arrangement properly recorded and approved by a City Company. Practising a new craft, mathematical instrument makers had to find a company as best they might; one method was to join a father's company, whichever it might be, under the patrimony arrangement. New companies were formed, of course : the Spectacle-Makers in 1629, the Clockmakers in 1631. But the mathematical instrument-makers were captured to a great and surprising extent by one of the Twelve Great Livery Companies, the Grocers. Once a master-apprentice succession was established, the instrument makers remained in the Company, and so a school was built up. This has been fully explored by Joyce Brown in her book on *Mathematical Instrument Makers in the Grocers' Company* (1979).

By a most fortunate chance, a uniquely important group of twenty scientific instruments by the first London makers has been preserved in the Museo di Storia della Scienza in Florence. These were taken to Italy in 1606 by Sir Robert Dudley (1574-1649), the son of Queen Elizabeth's favourite, the Earl of Leicester. As a young man, he was sponsored at court by his father, and studied navigation with Abraham Kendall, who was pilot to Dudley's expedition of 1594-5 to the West Indies. The following year, he joined the Anglo-Dutch fleet, known as the Counter-Armada, that sacked the port of Cadiz, in which engagement he was

knighted. After the death of Elizabeth, Dudley was involved in a lawsuit to prove himself the legitimate heir of Leicester. When this failed, he left England for good, and settled in Florence, at the court of the Medici. Already leaders in commerce, this powerful family were anxious to join the race to the New World, and were building up a fleet at the port of Leghorn (Livorno). The skills brought by Robert Dudley were therefore most welcome, and he earned high favour at the Medici court. His gifts as navigator and ship designer were embodied in his great, three-volume work, *Dell'Arcano del Mare*, published in 1646. This contains engravings and descriptions of a range of complex navigational instruments, as well as the first Atlas on the Mercator projection.

The Dudley instruments in Florence were made by Cole and Kynvyn, whose work has already been referred to, Augustus Ryther, and Charles Whitwell. Ryther was an engraver of distinction, and signed some of his maps "Augustinus Ryther Anglus" to distinguish himself from the Flemish engravers. His earliest signed work are the maps dated 1576, engraved for Christopher Saxton. A pack of playing cards is also attributed to him. In 1582, Ryther took as his apprentice for nine years Charles Whitwell (d.1611), who obtained his freedom of the Grocers' Company in 1590. Hood advertised on the title page of his book on the *Sector* that "the instrument is made by Charles Whitwell, dwelling without Temple Barre against St Clements Church". Whitwell engraved the illustrations for Hood's book, and did the same service for other authors. There are eight men among his known apprentices, the most famous being the incomparable Elias Allen (d.1655), who became free of the Grocers' Company in 1612 after serving for nine years. With Allen, the London trade in scientific instruments was well and truly established.

By 1600, the number of men trained as engravers had increased, and workshops had grown in number and size. Instruments became more complex and varied, with competition in producing new designs to catch attention and to compete with a rival. Earlier, craftsmen had worked in collaboration with the scholar-inventor; now they were to become capable of independent invention. Instruments for astronomy, time-telling, navigation, and surveying were created for economic reasons. There was,

too, a market among wealthy men interested in scientific matters, and elaborately embellished instruments were provided for their delectation. But this group is more obviously catered for by the products of the leading Continental makers rather than the English, whose instruments are austerely functional.

Elizabethan Scientific Instrument Makers		
Name	**Dates working**	**Instruments known**
Thomas Gemini	1540-62	7
V.C.	1554-57	2
Humfrey Cole	1568-91	26
Barthelmewe Newsum	1568-93	2
James Kynvyn	1570-1610	10
Augustine Ryther	1576-95	2
Charles Whitwell	1590-1611	29
Thomas Osborn	1590	1
T.H.	1596	1
Robert Beckit	1597	1
John Goodwin	1595-1610	3
William Senior	1600	1
R.G.	1600	2
T.W.	1602	1
Isaac Simmes	1610	3
Anonymous	16th C	9
	Total	*100*

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