Leonard and Thomas Digges: 16$^{\text{th}}$ Century Mathematical Practitioners

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Abstract

In 16th century England Robert Recorde (1510–1558)[1] and John Dee (1527–1609) were proponents of the applications of mathematics and set about a programme of public education. They claimed mathematics was useful and that advancement in the subject would contribute to the 'common wealth' of the nation. In this respect, Dee's close friend Leonard Digges (c1520–1559) produced practical manuals for navigators, surveyors, landowners, joiners, carpenters and masons, showing them how to improve their craft and introducing new instrumental inventions. After Leonard died his son Thomas (1546–1595) was tutored by John Dee, and received advanced mathematical instruction. Dee and Digges collaborated in various mathematical and astronomical works and made significant contributions to mathematics and astronomy, being responsible for an early version of the telescope. Thomas furthered the applications of mathematics in many practical, military and economic problems, being responsible for the organisation and administration of government projects. Leonard and Thomas Digges displayed understanding and ingenuity in their mathematical works, invented many new devices, promoted wider access to technical and scientific knowledge outside the universities, and were, through their works among the first to define the role of the 'mathematical practitioner' in English society.

A Brief Overview of 16$^{\text{th}}$ Century England

Henry VIII (1491–1547) designed palaces and fortresses with the help of craftsmen from Germany and Italy, with the help of shipwrights from Venice to increased his naval prestige. Henry's court provided an environment in which the mathematical arts were favoured as much for their display as for their practical and strategic use. Henry was succeeded by Edward VI who died in 1553 and Mary Tudor who married Philip of Spain in 1554. Four years later, Mary Tudor was succeeded by Elizabeth I. During these times England was not united, and the political ambitions of the Scots, the Welsh and the Irish caused domestic problems throughout the century. Claims to regions of France, the threat of Spanish invasion, and the Dutch rebellion against Spanish domination preoccupied English diplomatic and political activity, but in spite of these uncertainties, England's economic growth continued, largely due to the development of her sea power and the developing class of business and crafts people who saw opportunities in the practical applications of new technical knowledge.

[1]See Rogers (2004)

Leonard and Thomas Digges: their social context and mathematics

Leonard and Thomas Digges came from Kent where they had extensive estates. Thomas's publications carry his Coat of Arms, and in their books they refer to themselves as 'Gentlemen'. During the reign of Mary Tudor, Leonard was convicted of treason for his part in a rebellion against the Queen's marriage to Philip of Spain. Luckily, through the intercession of friends Leonard was pardoned and, after the succession of Elizabeth I in 1558, his confiscated lands and properties were returned.

In his lifetime Leonard published an almanac called *A Prognostication everlastinge of right good effecte*... (1555) which appeared in various editions throughout the century, and *Tectonicon* (1556), a text on mensuration and mathematical instruments. In addition to these two books, Leonard promised some other works whose appearance was prevented by his early death in 1559. A considerable amount of this material was later prepared for publication by his son, who also made additions of his own. Apart from the sections of the *Prognostication* and *Tectonicon* which are clearly Leonard's, it is impossible to tell how much of the publications by Thomas, are originally due to his father.

Astrology, Almanacs and Practical Mathematics

Almanacs of the period consisted of a mixture of astrological predictions, and traditional medical practices but the useful data was limited, and new almanacs appeared each year. Leonard Digges' *Prognostication* was a considerable improvement on these. The book opens with an *apologia "against the reprovers of astronomy and science mathematical"* where he states that *"the ingenious, learned and well experienced circumspect student mathematical receiveth daily in his witty practices more pleasant joy of mind than all thy goods (how rich soever thou be) can at any time purchase"*.[2] This book has important sections on the use of the quadrant, the mariners compass, dialling, making calendars, the influence of the moon on tides, times of eclipses, and it's data could be used to predict astronomical events over a longer period of time. In a later edition he shows a diagram of a Ptolemaic Earth-centred universe and the relative sizes and distances of the planets from the sun are given.[3] He states:

> I thought it mete also to put here this figure, shewing the placing comparing and distances each toforesayd Planetes in the heaven: whiche distances at my last publishing were thought impossible. This figure wittily wayed may confirme a possibilitie to agree until the true quantities, immediately before put forth, therfore not omitted here to be placed." However, the demonstration of these distances is not given because "it passeth the capacity of the common sorte.[4]

This book was very popular, and continued in publication into the early 17$^{\text{th}}$ century. Leonard also managed to publish *A Booke named Tectonicon* in 1556. This was a practical manual, *"most conducible for surveyors, landmeters, joiners, carpenters and masons"*.[5] It taught the measurement of land, the calculation of quantities of materials; wood blocks of various shapes, stone globes, pillars and steeples. The last section of the book shows how to construct an adjustable cross-staff with interchangeable sections, and *Tectonicon* remained in publication until 1692. Although he promised more, no other works are entirely his own. He wrote on arithmetic and mensuration and in his surviving papers on ballistics he shows

[2] 1557 (Folio 1 r & v.)

[3] 1576 (Folio 4 Bi).

[4] It is possible that John Dee's texts of 1550 and 1551 are the source of these estimates.

[5] 1556 Digges, L. *Tectonicon* Title Page.

by experiments that some of Tartaglia's[6] results were wrong. These ideas were used by his son in two books, *Pantometria* (1571) and *Stratioticos* (1579) and Thomas gave due credit to his father. Leonard Digges was a successful popularizer, a dedicated experimenter, and an important advocate of mathematics and its practical applications.

Leonard and Thomas Digges and their relationship with John Dee[7]

After Leonard Digges death in 1559, Thomas was brought up by Dee from 1559 to 1571. During this period Dee was living at Mortlake on the river Thames, and was being visited by eminent scientists and mathematicians of the time, as well as travelling to the continent. Given this situation, it was not surprising that Thomas should inherit many of John Dee's mathematical ideas. Thomas often refers to Dee as his "second parent in mathematics and astronomy".[8]

John Dee (1527–1609) had entered Cambridge and gained his B.A. in 1546. In 1548 he made the first of many visits to Europe. During this time, he met Gemma Frisius, Gerhard Mercator, Pedro Nunes, lectured in Paris, and wrote two texts on astronomy before he returned to England in 1552. Dee was the technical adviser to many voyages of discovery, training the navigators, developing navigational instruments and experimenting with William Gilbert (1544–1603) on the properties of the magnet. He was also involved in astrology, alchemy, and the occult, and is thought to be the model for Prospero, in Shakespeare's play *The Tempest* (Usher 2002).

Dee wrote the *Praeface* to Billingsley's 1570 edition of *Euclid*. He assisted with the translation, wrote summaries of the various books, and made some extra diagrams that could be copied and folded into three-dimensional representations. Dee's *Praeface* is an exposition of a neo-Platonic philosophy, where mathematics arises from innate abstract principles which can be signified by natural things.[9]

> All thinges (which from the very first originall being of thinges, have been framed and made) do appeare to be Formed by the reason of Numbers. For this was the principall example or pattern in the minde of the Creator. ... By Numbers propertie therefore, of us, by all possible meanes (to the perfection of the Science) learned, we may both winde and draw our selves into the inward and deep search and vew, of all creatures distinct virtues, natures, properties and Formes...[10]

The *Praeface* proposed a programme of practical mathematics of service to the 'common wealth' at large. He advocated the translation and dissemination of scientific work and showed a clear understanding of experimental method. His practical methods appealed to the new class of artisans and technical craftsmen by justifying for their mathematical activities.

Thomas Digges: Mathematics and Publications

Thomas was also a gentleman of independent means and although he dedicated his books to influential men, this was a gesture of friendship, rather than seeking patronage. Later, in 1572, Thomas became a member of Parliament, and was subsequently involved in government administration, the reconstruction of Dover Harbour, and military affairs.

[6] Probably both Tartaglia's *Nova Scientia* (1537) and *Questi et Inventioni Diverse* (1546) were available.
[7] For detailed discussion on Dee's influence, see Johnson, S. (2006) and MHS Oxford, and on Dee see JDS.
[8] 1573 Digges, T. *Alae* (2Arecto and B3recto) and in 1579 Digges, T. *Stratioticos* p. 190
[9] 1570 Dee, *Mathematicall Praeface* (ij verso)
[10] 1570 Dee, *Mathematicall Praeface* (j)

Thomas's first publication was *A Geometrical Practise, named Pantometria...* (1571). The major part of this text on surveying and mensuration had been written by Leonard, and Thomas acted as an editor, leaving the substance of the work unchanged. The work in three books describes measuring distances, heights, areas and volumes using different instruments in both civil and military contexts. With this book, Thomas published his treatise on the five Platonic solids, an original and impressive work where he made his debut as a mathematician.

Pantometria begins with a series of geometrical definitions and is arranged in three books: *Longimetria* is the measurement of lengths, of the heights and distances necessary for surveying, the description and use of the quadrant and carpenter's square and the invention of the azimuth theodolite. Here we find a reference to the 'perspective glasses' apparently invented by his father. He also talks about the flight of a canon ball, and criticises Tartaglia for errors due to lack of experiment. The final part of this book consists of detailed instructions for drawing accurate surveyors plans.

The second book, *Planimetria* is about determining areas of plots of land; it also shows ways of finding areas of circular and other irregular shapes. The final book, *Stereometria* gives instructions for determining volumes of various shapes, pyramids, prisms, cones, columns, frustrums, spherical caps, and hollow objects. Finally, he shows an ingenious method for determining the volume of a barrel, given a smaller vessel of the same shape. The work is a comprehensive display of standard techniques for mensuration, including new techniques and ingenious devices one of which is the first English description of an azimuth Theodolite.

Thomas' treatise *A Mathematical Discourse of Geometrical Solids* is a spectacular display of ingenuity and geometrical indulgence. In the preface he claims to

> ...conferre the Superficiall and Solide capacities of these Reglare bodies with their Circumscribing or inscribed spheres or Solids, & Geometrically by Algebraicall Calculations to search out the sides, Diameters, Axes, Altitudes and lines Diagonal, together with the Semidimetients of their Equiangle Fases, containing or contained Circles, ... with numbers Rationall and Radicall expressed ... Finally I shall ... set for the forme, nature and proportion of other five uniforme Geometricall Solides, created by the transformation of the five bodyes Regular or Platonicall...[11]

This he does with skill and ingenuity. He also claims that he will produce another volume demonstrating the *"Conoydall, Parabollical, Hyperbollical and Elleptical circumscribed and inscribed bodies"*[12] of various spherical solids, but this never appeared. The *Discourse* has definitions which are the basis for the calculation of the lengths of the lines, areas and volumes, and he then presents 96 pages of 'theorems', all of which give rational and irrational results, stated without proofs. In developing these highly technical results, he shows how they can be achieved 'arithmetically and geometrically'. This indicates that Thomas had studied Dee's recent works,[13] and was determined to show his prowess as an original mathematician.

Astronomy and Copernicanism

In 1572 a new star appeared in the constellation Cassiopeia. It became visible during the day, but disappeared after 16 months. A year later Thomas Digges published *Alae seu scalae mathematicae*,[14] a work on the position of the new star. Digges' work includes observations and trigonometric theorems used to determine the parallax[15] of the star. Dee published a

[11] 1571 Digges, T. *Pantometria* (end of the third book; verso)

[12] 1571 Digges, T. *Pantometria* (Tj)

[13] Dee's lost *Tyrocinium Mathematicum* was largely concerned with the theory of irrational magnitudes: Euclid, *Elements* (London, 1570), f. 268 recto & verso.

[14] This was in Latin in order to show other astronomers that this was a serious technical work.

[15] Parallax is the shift of an object against a background caused by a change in the position of the observer.

similar work, *Parallaticae commentationis praxeosque nucleus quidam* (1573) and the two were often sold together as a single volume. Digges believed that the distances to the stars varied, and realised that when no parallax could be determined between the new star and the fixed stars, it was a very great distance away. The idea that the universe was not perfect and immutable began to spread, and three years later Thomas Digges published an 'addition' to his father's *Prognostication*, entitled *A Perfit Description of the Celestiall Orbes* (1576) where he translated and extended the principal passages from Book 1 of Copernicus for an English audience, and showed how he questioned 'received wisdom' of with actual experiments:

> ...in a ship under sail a man should softly let a plummet down from the top along by the mast even to the deck: this plummet passing always by y^e straight mast, seemeth also to fall in a right line, but being by discourse of reason moved, his motion is found mixt of right and circular.[16]

Here he talks about an infinite universe, and the diagram shows stars at varying distances with the description; *"This orbe of stares fixed infinitely up extendeth hit self in altitude spericallye ... farre excelling our sonne both in quantitye and qualitye..."*[17]

Thomas is clearly committed to the Copernican system and shows he 'approves' the system by geometrical demonstrations. The technical details of the demonstrations are in Latin in his *Alae*, but he must have considered that the few objections to the old system in the first pages of his *Perfit Description* were enough to persuade his English readers.

OPTICS AND THE TELESCOPE

The effects of lenses were known from early times. Roger Bacon (c. 1214–1292) had reported that it was possible to *"make glasses to see the Moon large"* (Rienitz 1993) and in the fifteenth century, artists could use a concave *"mirror-lens"* and to view their subjects. (Hockney 2001) Leonard Digges was a keen experimentalist who is now regarded as the inventor of the "Perspective Trunk", which comprised a plano-convex lens with a spherical mirror (Ronan 1992). These devices were in use by 1570, as reported by John Dee, and by Leonard and Thomas Digges in *Pantometria.* The title page has a reference to "Perspective Glasses" and in the Preface, Thomas refers to his father's use of "Proportional Glasses."

> ...my father ... hath by proportional Glasses duely situate in convenient angles, not onely discovered things farre off, read letters, numbered pieces of money with the very coyne and superscription thereof, ... but also seven myles of declared what hath been doon at that instante in private places:[18]

This may sound exaggerated, but it is supported by Dee's claim in his *Praeface.* The most important section of *Pantometria* is in Chapter 21 of the first book:

> But marveylouse are the conclusions that may be preformed by glasses concave and convex of circulare and parabolicall formes using for multiplication of beames sometime the ayde of glasses transparent,... These kinde of glasses ... may not onely set out the proportion of an whole region, ... but also augment and dilate any parcel thereof, so that whereas at the first appearance an whole towne shall present itself so small and compacte ... ye may by application of glasses in due proportion cause any peculiare house or roume therof dilate and shew itself in as

[16] 1576 Digges, T. *A Perfit Description* (N3 verso).
[17] 1576 Digges, T. *A Perfit Description* from the diagram (M1 Folio 43).
[18] 1571 Digges, T. Pantometria (preface Folio Aiij verso)

> ample forme ... so that ye shall discerne any trifle, or read any letter lying there open, ... although it be distant from you as farre as eye can discrye:[19]

This effect would have been possible at a distance of seven miles with a magnification of eight times, as a recent test has shown. (Ronan 1991/2/3)[20] There is also an independent report on the subject made by William Bourne, an expert in navigation and gunnery quoted in Ronan (1991). It is now accepted that these are the earliest records of the invention of a telescope in Western Europe (van Helden 1997).

A Military Compendium

In 1579 Thomas published *An Arithmeticall Militarie Treatise named STRATIOTICOS...* based on work by his father and *"Augmented, digested and lately finished by THOMAS DIGGES, his sonne..."*

The first part of *Stratioticos* contains an advertisement for the works Thomas had already published, and for books to be published. These were: a treatise on Navigation and another on the Building and Design of ships; Commentaries on Copernicus; A book of Dialling; A Treatise on Artillery with instruments for ranging and accurate firing of guns; and a Treatise on Fortification, but none of these ever materialized as complete works.

Stratioticos consists of three books:

The first book 'Arithmeticall' has operations in integers and fractions, square and cube roots, and rules for the summation of arithmetical and geometrical progressions. The rule of proportion, inverse proportion and double application of the 'golden rule' are all founded on Proposition 19 of Euclid Book VII.

The seond 'Algebraicall' has an explanation of the cossical numbers and their representations; Operations in integers and fractions 'Denominate or Cossical'; Equations with a chapter on the 'rule of coss'; and five rules for the solution of quadratic roots. He begins by explaining the progression of the powers of a root and introduces a series of symbols invented by his father to signify the root, square, cube, etc. He shows how to work the basic arithmetical operations, and deals with the four rules of 'cossical fractions'. Equations are defined as *"... nothing else but a certain conference of two numbers being in value Equal, and yet in multitude and Denomination different"*,[21] and shows how to transpose numbers in equations so that you may *"... reduce one side of the Aequation, to one particular Cossical Number."*[22] The Rule of Coss is praised to replace all others like proportion, false position, etc., and he gives some examples of linear problems and shows how to solve them. Afterwards, he shows how to solve quadratics using five rules. Rules 1 and 2 refer to the simpler cases where $x^2 = p$ and $x^2 = p/q$.

Rule 3 shows the procedure for solving $x^2 = 6x + 27$:

"The moytie of 6 is 3, that Squared, is 9, which added to 27 maketh 36, the Roote Square of that is 6, whereto aioying 3, the moytie first used, I make 9 the Radix of that Aequation."

Rule 5 demonstrates the procedure for solving $x^2 = 14x - 33$:

"The moytie of the number of Primes is 7, that squared maketh 49 from this I deduct 33, the abstract number, resteth 16 whose Roote 4 added to 7, the Moytie Fundamentall, maketh 11, the greater Roote, deduct the same 4 from 7, resteth 3 the lesser Radix.

The truth of whereof is thus apparent, square 11 ariseth 121, the square which should be equall to14 Rootes lesse 33, 14 times 11 maketh 154 the number of the Rootes, from this deduct 33, the abstract number resteth 121 your Square. In like sort, the lesser Roote

[19] 1571 Digges, T. *Pantometria* (Folios Fij verso, Gj, recto and verso, and Gij)

[20] The 'Digges telescope' was displayed in a BBC television programme in 1992. A similar instrument was constructed at Leicester University, its field of view is very small, confirming William Bourne's report.

[21] Digges, T. 1579 (page 44 Gij verso)

[22] Digges, T. 1579 (page 45 Giij)

3 squared maketh 9. Now 14 of these Rootes are 42, from whiche deduct 33 resteth 9 the Square. And hereby it is manifest, that both the one and the other are true Rootes of this Aequation, and moe than these is impossible to finde."

In Rule 3, he adds the root +6 to 3 (the moitie) getting 9 for a solution, not using −6, the negative root which would have given him −3 as a second solution to the equation. In the second example, he subtracts the negative root of 16 from 7 leaving a positive result, 4. The algorithm demonstrated here has a long history, with roots in Mesopotamian and Indian solutions for area problems. The text is still 'rhetorical' and we can see the development of algebraic notation and technical language where he borrows terms from German and French, and makes up some of his own.

The Geometry of War: Gunnery and Ballistics

Early writers on ballistics claimed the trajectory of a cannon ball was a straight line, the result of an initial impetus that quickly dissipated, and taken over by the 'natural' fall back to earth.[23] *Tartaglia* (1546) later admitted errors in his theory and declared that the trajectory of a projectile was curved in parts and only straight on its descent. Thomas Digges clearly indicated the problems in his *Pantometria* of 1571, demonstrating that to achieve consistent results with gunnery requires both experiment and sound mathematical knowledge.[24]

He devoted the final section[25] of *Stratioticos* (1579) to artillery. The four major problems were "Powder, Peece (the canon), Bullet, and Randon"(angle of elevation). Other variables are 'rarity' of the air, wind direction, how to make a gas tight fit, the gun mounting, irregularities in the bore, and the expansion of the barrel. He made experiments to achieve standardisation, and covered the calibration and ranging of guns and the trajectories of the shot. He was an accurate observer, proposing further investigations into the nature of ballistics and insisting that without practical experience, authoritarian statements about the flight of the bullet were useless. He agreed the trajectory of the shot was composed of violent and natural motion, and suggested that its shape was a conic section, and that the angle between the original elevation and the path of the shot was continually changing.

Dover Harbour: the Mathematics of Surveying and Engineering

Due to the Spanish threat from the Netherlands, Dover harbour had to be rebuilt, and by 1583 Thomas Digges, and a number of other 'mathematical practitioners' became involved in a major construction project. Earth had to be moved, jetties, locks and sluices designed, materials brought to the site, and workmen organised. Since there was very little experience of constructing anything on such a scale,[26] Digges and his companions found themselves drawing up plats,[27] inventing new working procedures, and daily calculating. The project was overseen by the Privy Council, who did not have the mathematical skills, so practitioners like Digges gained considerable power and responsibility. From 1586, Thomas Digges served in the army sent to the Low Countries, with responsibility for organising the supplies and the pay for the army.[28] He returned to England in 1588 where

[23] Tartaglia's *Nova Scientia* (1537) showed a straight line of projection upwards at an angle, a circular arc, and then a straight line of descent. By experiment, he discovered that the maximum range was attained with an angle of 45°. In his *Questi et Inventioni Diverse* (1546) he stated that a body could possess violent and natural motion at the same time, and that only natural motion was vertical and in a straight line. Thus, unless the canon was fired straight upwards, the projectile had to describe a curved path. (Cuomo 1998)

[24] Digges, T. *Pantometria* Chapter 30 (Jiy verso)

[25] 1579 Digges, T. Stratioticos Chapter 18, pages 181–189. Also see 1571

[26] For a detailed description of this project, see Johnston, S. PhD Chapter 5 (MHS)

[27] A 'plat' could be anything from an 'artists impression' of the work, to a detailed geometrical survey.

[28] 1587 Digges, T. *A Briefe Report of the Militarie Services...* and 1590 *Briefe and true report of the Proceedings of the Earle of Leycester...*

he produced further editions of his Stratiaticos (1590) and Pantometria (1591). He died in 1595.

Thomas Digges' reputation stands as a consummate mathematician and a person whose life was devoted to the service of his country, but most of all as one whose vision of the power that mathematics brings when it is applied to practical problems set the path for others to follow in the education of artisans and craftsmen.

Conclusions

In spite of the social upheaval and intrigue much was achieved by the English mathematical practitioners of the sixteenth century. Publication in the English language was a means to advertise the practical uses of mathematics, and to define mathematical ideas, activities and techniques free from occult practices and useful for the common good. The key individuals involved in this transformation were Recorde, Dee, and Leonard and Thomas Digges, whose lives overlapped to a remarkable degree. However, there were many more people involved who have not yet had the attention of historians. Their work was a conscious effort to spread the utility and advantage that mathematics could bring to daily life through their books, and their vision of a programme of public education. The friendship of Leonard Digges with John Dee and the subsequent mathematical nurturing of Thomas Digges was a unique set of circumstances. Dee brought a considerable amount of scientific knowledge to England and established mathematics as a credible science. Other contributions were his advocacy of the translation of foreign works, and public education. Leonard Digges was a competent mathematician who put practical mathematics into publication, and after his death Dee encouraged his son's development. Thomas' first publication was a brilliant essay in abstract mathematics, but it had a practical edge. Thomas, like his father, was an experimenter and inventor who insisted that practical problems required sensible solutions, and theoretical proposals needed to be tested in the real world. Thomas Digges did much to define the concept and role of the 'mathematical practitioner' in the latter part of sixteenth century England, and lay the foundations for the development of technical education in the century to come.

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WWW Resources

– The John Dee Society (JDS) (Calder Thesis) http://www.johndee.org/

– Museum of the History of Science, Oxford (MHS) http://www.mhs.ox.ac.uk/

– Stephen Johnston (Assistant Keeper) http://www.mhs.ox.ac.uk/staff/saj/