Chapter 2

Thomas Harriot in the Twenty-First Century:

25 Years of the Harriot Lecture

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A little over forty years ago, in 1974, John W. Shirley published a collection of essays *Thomas Harriot: Renaissance scientist*, which presented Harriot as a ‘key figure at the time when the new science of logic, reason, mathematics, and experiment was coming into being’. [[1]](#endnote-1) In a rather uncharitable essay-review of this volume in the journal *History of Science* in 1975, entitled ‘In search of Thomas Harriot’, the late Tom Whiteside criticised its contributors for not doing sufficient justice to their subject. If anything, Whiteside’s praise of Harriot was more fulsome than any of the contributors to that volume. For Whiteside, Harriot ‘possessed a depth and variety of technical expertise which gives him good title to have been England’s – Britain’s – greatest mathematical scientist before Newton’.[[2]](#endnote-2) Coming from Whiteside, who knew Newton’s manuscripts better than anybody at that time, this was high praise indeed; it came from a man who was not customarily given to hyperbole. Whiteside’s review acknowledged the scholarship of John Shirley and Johannes Lohne in the 1950s which, he said gave us a ‘true appreciation of Harriot’s expert skill and inventiveness in the physical sciences’.[[3]](#endnote-3) However, he did feel that some very pressing questions had been neglected by Shirley and his contributors. ‘Such questions’, he says, ‘as how near did Harriot come to creating a viable theory of ... “local” motion and collision ... are not even asked, let alone answered’.[[4]](#endnote-4)

**In search of Thomas Harriot**

A great deal of work has been done on Harriot since 1974, and yet in many ways we are still ‘in search of Thomas Harriot’. In this chapter I will reflect briefly on the advances made in our understanding of Harriot over the last forty years, and celebrate the twenty-five years of Harriot lectures at Oriel, which have made such a signal contribution to those advances. By surveying some of the significant moments in Harriot studies in the past decades I hope to come to an understanding of what Harriot means for the twenty-first century, and to reflect on what remains to be done in the decades to come. Much has been achieved, but many questions remain to be asked.

 There is no question that one of the key areas of Harriot’s achievement which has been properly elucidated since Shirley’s time is Harriot’s algebra. In her book *A discourse concerning algebra: English algebra to 1683*, published in 2002, the late Jacqueline Stedall reassessed the contribution that Harriot had made to this subject. The great Oxford mathematician John Wallis held Harriot in very high esteem, but he has been criticised by later historians – who only knew Harriot’s posthumously published writings – for partiality or chauvinism.[[5]](#endnote-5) A careful examination of Harriot’s papers, however, suggested a different story: ‘[A]mongst the disarray of Harriot’s manuscript sheets’, Stedall wrote, ‘we have the scattered pages of an invaluable treatise, a treatise that extended the contemporary understanding of polynomial equations’.[[6]](#endnote-6) Wallis had somehow divined from the published version of Harriot’s algebra what Harriot had really been trying to say. Wallis, Stedall argued, ‘saw the true magnitude of what Harriot had done’. [[7]](#endnote-7)

 In *The greate invention of algebra*, published in 2003 – using some hints from Cecily Tanner and Muriel Seltman – Stedall was able to reconstruct this unpublished treatise on equations from 140 scattered sheets in the surviving manuscripts.[[8]](#endnote-8) Using Nathaniel Torporley’s manuscript treatises the *Congestor analyticus* (Torporley’s incomplete attempt at reconstructing Harriot’s treatise) and the *Corrector analyticus artis posthumae Thomae Harrioti*, which criticizes Harriot’s posthumously published treatise on algebra edited by Walter Warner (the *Artis analyticae praxis*), Stedall was able to able to present the fullest possible account of Harriot’s algebraic solutions of polynomial equations.[[9]](#endnote-9) Stedall’s volume was complemented by the first republication of the *Praxis* since 1632, in the shape of Robert Goulding and Muriel Seltman’s translation, published by Springer in 2007.[[10]](#endnote-10) Both of these publications showed Harriot’s initial debt to the algebraic work of the French mathematician François Viète, but also the extent of his own original contributions.[[11]](#endnote-11) Viète’s algebra was, as Stedall observed, ‘the foundation of Harriot’s’,[[12]](#endnote-12) and he had privileged access to some of it even before it was published, via his friend Torporley, who had acted as Viète’s amanuensis in the mid-1590s.[[13]](#endnote-13) However, not only did Harriot rewrite sections of Viète’s *De numerosa potestatum ad exegesin resolutione* (1600) in his own notation, but he also ‘explored for himself the theoretical underpinnings of Viète’s method, and so developed his own treatment of the structure and solution of polynomial equations’.[[14]](#endnote-14) Harriot made particular advances, Stedall argued, in the relationships between roots and coefficients, and while Viète analysed equations in terms of ratios, Harriot ‘saw the possibility of writing polynomials as products of factors of lower degree’.[[15]](#endnote-15) He also developed an innovative method for removing a cube term from a quartic equation which is not found in the work of any of Harriot’s predecessors.[[16]](#endnote-16) Harriot emerges from Stedall’s study, as a much more creative algebraist than those who judged him solely on the basis of his printed work imagined.

 As Stedall’s painstaking reconstruction of the treatise on polynomial equations suggests, Harriot’s surviving manuscripts are thin in terms of free-standing manuscript treatises. However, Stedall – together with her colleague Janet Beery – was instrumental in publishing one such work, the *De numeris triangularibus. et inde de progressionibus arithmeticis magisteria magna*, which survives in British Library, Additional MS 6782. The *De numeris* is written almost entirely in notation, so in this project Stedall and Beery published the manuscript in facsimile (which is perfectly legible and has the added benefit of preserving the layout of the original), together with a long introductory essay.[[17]](#endnote-17) The *De numeris* presents an algebraic method for interpolating tables by means of constant differences, which (as Stedall and Beery show) was shared and discussed by English mathematicians throughout the seventeenth century, although the means by which it was disseminated was largely informal.[[18]](#endnote-18) Harriot found his way to his own arithmetical theories via those of Boethius and Jordanus (republished together in 1503 by Jacques Lefèvre d’Étaples) and those of more recent mathematicians such as Francesco Maurolico, Michael Stifel, and Girolamo Cardano.[[19]](#endnote-19) Through these earlier mathematicians, Harriot became interested in the properties of triangular numbers, and specifically how they could be used to devise a method for interpolation. That is to say, how given a difference table of arithmetic progressions, one could devise a method for interpolating new values between the existing values.[[20]](#endnote-20) This method had many potential applications, and Stedall and Beery believe that Harriot began thinking about this problem during the period when he was working on tables of meridional parts (required to calculate the accurate position of a ship at a sea following a constant compass bearing), and had arrived at an algebraic solution by 1614.[[21]](#endnote-21) Harriot used his new method to generate polyhedral numbers,[[22]](#endnote-22) and in his work on polynomial equations involving the sums of squares, cubes, or higher powers,[[23]](#endnote-23) which were later to become important to the development of the integral calculus.[[24]](#endnote-24) Stedall and Beery trace the dissemination of Harriot’s method from his immediate colleagues Nathaniel Torperley and Walter Warner, to a wider circle of mathematicians, including Henry Briggs, Charles Cavendish, John Pell, John Collins, and Nicolaus Mercator.[[25]](#endnote-25) Although it was not widely known, the fact that ‘Harriot’s method of differences was still in use amongst English mathematicians almost sixty years after Harriot invented it’, is not without significance, and Harriot’s method was not surpassed until the work of Newton and Gregory in the late seventeenth century.[[26]](#endnote-26) These studies show that Harriot was a significant mathematician, whose work more than justified the high opinion entertained about it by Charles Cavendish and John Wallis.

 Another heroic work of reconstruction, which has fulfilled some of the enthusiastic assessments of Shirley and his contemporaries, is Matthias Schemmel’s *English Galileo*, published in 2008.[[27]](#endnote-27) Like Stedall, Schemmel had to literally piece together all of the existing papers on free fall and ballistic trajectories, scattered throughout Harriot’s papers – in this case running to over 180 folios. In doing so, Schemmel reveals Harriot to have been a significant figure in pre-Classical mechanics, someone who wrestled (like Galileo) with intractable problems using the mathematical and natural philosophical tools available to him at the time, and who used experiments and the ‘shared knowledge’ of practical men to shape his investigations.

 Although – as has often been noted – most of Harriot’s work remains unpublished, and could therefore be seen as a ‘dead end in the history of science’, Schemmel argues that Harriot’s manuscripts gain in value when viewed from the perspective of ‘historical epistemology’.[[28]](#endnote-28) This approach – associated with the work of historians of science at the Max Planck Institute for the History of Science in Berlin – is less concerned with individual contributions to scientific knowledge, and focuses instead on the ‘shared knowledge’ of mathematical practitioners in early modern Europe, and how it facilitated the shift from pre-classical to classical mechanics.[[29]](#endnote-29) From this viewpoint, ‘major’ figures like Galileo retain their significance, but the work of ‘lesser known contemporaries’ (like Harriot) are seen as important for establishing a fuller understanding of the historical process. While Schemmel does not want to argue that the English mathematician was a ‘neglected Galileo’, Harriot nonetheless emerges from this study with some credit. Harriot and Galileo are seen as similar figures, ‘occupied with similar problems’, both of whom have ‘shortcomings when viewed from within the classical framework’.[[30]](#endnote-30) Schemmel’s close analysis of Harriot’s research methods reveal a figure in whose work ‘we […can] discern several of the crucial insights for which Galileo was famous’. [[31]](#endnote-31) Schemmel, however, seeks to avoid the anachronistic teleology of ‘progress’ towards classical mechanics, and the invidious canonical logic of comparing ‘major’ to ‘minor’ figures, attempting instead to show that both the English and the Italian mathematician drew on a shared legacy composed of Aristotelian physics, the mediaeval *calculatores*, ancient mathematics, and the knowledge of practitioners, such as engineers and gunners .[[32]](#endnote-32) This shared knowledge, as he so aptly puts it, ‘defined a space of possible alternative solutions’ available to early modern thinkers.[[33]](#endnote-33)

 Schemmel shows how Harriot (like Galileo, Descartes, and Beeckman) approached the question of motion using the tools provided by the mediaeval *calculatores* and the geometrical representations of motion popularized by Nicolas Oresme,[[34]](#endnote-34) and was able to arrive at a satisfactory understanding of the time-squared law, although he was ignorant of the ‘conditions of its mathematical validity’.[[35]](#endnote-35) Harriot, however, quickly realized that while these representations were adequate for capturing ‘uniformly difform’ motion with respect to time, they were unable to do the same with respect to space.[[36]](#endnote-36) Searching among the known curves of the time, Harriot alighted (possibly with the aid of some hints from Thomas Digges’s *Stratioticos* of 1579) upon the parabola as a likely candidate for representing projectile trajectories.[[37]](#endnote-37) Schemmel shows how Harriot turned to experiments with falling bullets and a balance to decide whether the law of motion of falling bodies was with respect to time, or to space, and used geometrical diagrams – which represented both his theoretical calculations (using arithmetical proportions and algebraic tools) and his experimental findings – as exploratory research tools rather than as mere descriptions of motions. By comparing calculated and experimental values, he was able to conclude that the motion of fall obeys the law of time proportionality.[[38]](#endnote-38)

 Schemmel also shows that, like Galileo, Harriot’s work was enmeshed in ‘practitioners’ knowledge’, and that it embodied the fruitful ‘union of practical mathematician and natural philosopher’ which was so important in this period.[[39]](#endnote-39) Schemmel shows how Harriot began his research on projectile motion by harvesting the empirical findings from practical treatises by Niccolò Tartaglia, William Bourne, Luys Collado, and Alessandro Capobianco, rescaling their results in order to facilitate comparison.[[40]](#endnote-40) He also shows that Harriot was prepared to rethink his mathematical results if they failed to capture practitioners’ knowledge,[[41]](#endnote-41) arriving at results that are ‘amazingly similar’ to modern trajectories.[[42]](#endnote-42) Attentive as he was to practical knowledge, Schemmel’s analysis reveals how Harriot made creative use of recently revived ancient mathematics in his work. Thus he used the theory of extrusion from Archimedes’s *On floating bodies* to explain differences in the velocities of falling bodies in terms of buoyancy,[[43]](#endnote-43) and used Apollonius’s work on conic sections to establish maximum ranges in relation to angles of elevation,[[44]](#endnote-44) and to prove that all projectile trajectories are parabolic.[[45]](#endnote-45)

 Schemmel’s study thus shows how Harriot used the existing knowledge base available to him to move from a concept of motion which was basically Aristotelian in the 1590s to one that saw the compound motions of projectiles as a combination of the inclined plane and the balance by 1606, a move which effectively abolished the Aristotelian distinction between natural and violent motion.[[46]](#endnote-46)

 The reconstruction work of Stedall and Schemmel in 2003 and 2008 are probably the two most significant steps towards a fuller understanding of Harriot’s legacy, and provide an inspiring example for those who follow after them. If this were not enough, Stedall and Schemmel, together with Robert Goulding, have acted as editors of the Harriot Online Project, supported by a team of technical advisors at the Max Planck Institute, and currently hosted by the ECHO Cultural Heritage Online website. This project – which is still ongoing – seeks to make available high-quality digitized images of all of Harriot’s papers, together with transcriptions and commentaries. As a tool for future Harriot researchers, the finished project will be of inestimable value, and make possible the kinds of reconstructive scholarship at which Stedall and Schemmel have excelled.

**The Harriot lectures, 1990-2015**

It is no surprise, then, to note that both Schemmel and Stedall made important contributions to the series of 23 lectures hosted by Oriel College, beginning with David Quinn’s ‘Thomas Harriot and the problem of America’, delivered on 7 May 1990. A significant number of these lectures have now been published in two important volumes edited by the *éminence grise* of theHarriot Lecture, Professor Robert Fox: *Thomas Harriot: an Elizabethan man of science* published in 2000, and *Thomas Harriot and his world: mathematics, exploration, and natural philosophy in Early Modern England*, published in 2012.[[47]](#endnote-47) The second of these two volumes includes pieces by Stedall and Schemmel on their larger projects, based on lectures they gave in 2002 and 2005 respectively. But the two volumes together present a wide range of other valuable perspectives on Harriot, which reflect recent historiographical shifts in the history of science and mathematics.

 Obviously, given the constraints of space, I am unable to rehearse the themes of all 23 lectures, so what follows will of necessity be a brief, and rather partial response to those lectures which I feel have advanced our understanding of Harriot. I would like to begin, perversely, with one of the lectures that was not published. In 2007 Stephen Johnston’s lecture ‘Thomas Harriot and the English experience of navigation’, drew our attention to an aspect of Harriot that has sometimes been forgotten: Harriot as a mathematical practitioner. Johnston situated Harriot in a world that his own work has done much to reconstruct. In his 1994 Ph.D. thesis ‘Making mathematical practice’,[[48]](#endnote-48) Johnston radically overhauled Eva Taylor’s concept of the ‘mathematical practitioner’,[[49]](#endnote-49) seeking to identify a culture of mathematical practice in Elizabethan England, in which men from very different backgrounds engaged in a broad range of Renaissance mathematical activities, including surveying, navigation, gunnery, architecture, and shipbuilding.[[50]](#endnote-50) Johnston’s lecture made us think again about the impact that the Roanoke voyage and English maritime exploration more generally had on the young Oxford-trained mathematician. This aspect of Harriot was also stressed by Pascal Brioist in his 2009 Harriot lecture, ‘Thomas Harriot and the worlds of practice’, which looked in detail at Harriot’s intense scrutinizing of the Elizabethan sailing ship as a complex assemblage of mechanical devices. Harriot’s notes on sails and rigging, bear vivid testimony to what Brioist calls his ‘special capacity to absorb all sorts of practical knowledge’.[[51]](#endnote-51) The 1995 lecturer Jim Bennett, in his lecture on ‘Thomas Harriot’s place on the map of learning’, brought Harriot into a complex but fruitful historiographical focus. The disappointment that some historians of science felt when confronted with Harriot’s work, he argued, was largely the product of ‘unhelpful perspectives’ and ‘inappropriate historiography’. Harriot, he said, ‘had become a disputed property, caught between different ways of viewing the mathematics and natural philosophy of the period’.[[52]](#endnote-52) While Whiteside unequivocally saw Harriot as a ‘mathematical scientist’, Bennett rejected such anachronism. ‘Harriot the scientist is an impossible characterization for the period’, he argued, whereas ‘Harriot the mathematician’ was ‘clear and evident’.[[53]](#endnote-53) Like Johnston, Bennett saw Harriot as a product of the ‘remarkable vigour of practical mathematics ... in the fifteenth and sixteenth centuries’. While he resisted the attempts of historians like Robert Kargon to piece together Harriot as a natural philosopher,[[54]](#endnote-54) he was interested in what happens when Harriot the mathematician is drawn into natural philosophical questions.[[55]](#endnote-55)

 For me, one of the most enduring products of the Harriot lectures is precisely the exploration of this historiographical crux about Harriot as mathematician or natural philosopher. This became clear in the two lectures of 2004 and 2005. In 2004 Matthias Schemmel gave his lecture ‘The English Galileo: Thomas Harriot and the force of shared knowledge in early modern mechanics’, while in 2005, John Henry responded with a lecture entitled ‘Why Thomas Harriot was not the English Galileo’. Schemmel and Henry have very different conceptions of Harriot’s career. For Schemmel, Harriot’s work on projectile trajectories and free fall makes an instructive parallel with the natural philosophical achievements of Galileo. Schemmel’s historical epistemological approach attends to the different ‘inferential pathways’ followed by Harriot and Galileo in their works on mechanics based on a very similar body of ‘shared knowledge’.[[56]](#endnote-56) Working independently on the same ‘challenging problems’ in ballistics, Schemmel argues, Harriot and Galileo raised ‘virtually identical questions’ about central problems in mechanics.[[57]](#endnote-57) Schemmel points out that Harriot’s knowledge of free fall and the shape of ballistic trajectories by 1621 was essentially the same as Galileo’s in 1638, with both employing the same inclined plane conception of projectile motion.[[58]](#endnote-58) If anything, he argued, Harriot was ‘more successful than Galileo in consistently relating the concept of velocity to the graphical representation of motion’. [[59]](#endnote-59)

 Henry does not explicitly refute Schemmel’s claims. But he argues that while Galileo amalgamated ‘speculative natural philosophy with mathematical and experimental traditions’, Harriot ‘remained first and foremost a mathematical practitioner’.[[60]](#endnote-60) Though conceding that there are some elements of Harriot’s work which could be construed as natural philosophical – his work on optics, impacts, and atomism – he says that ‘Harriot was willing to play the natural philosopher sometimes’[[61]](#endnote-61) and ultimately sees Harriot’s forays into natural philosophy as either a failure or a symptom of his ‘uncompromising perfectionism’.[[62]](#endnote-62) For Henry, Harriot must be excluded from a list of seventeenth-century figures (like Galileo and Descartes) who were both mathematicians and natural philosophers, who mediated between what Jim Bennett has called ‘the mechanics’ philosophy’ and the mechanical philosophy because his work shows little interest in causal explanations.[[63]](#endnote-63)

 Robert Goulding’s 2001 lecture painted a very different picture. Harriot’s work on optics, Goulding argues, ‘were connected with his abiding natural philosophical concern with the structure of matter’,[[64]](#endnote-64) and he shows that Harriot’s understanding of refraction was based on an atomistic model,[[65]](#endnote-65) and that his optical experiments should be seen as a ‘species of alchemical experimentation’.[[66]](#endnote-66) The historical assessment of the sixteenth and seventeenth centuries, and the complex relationship between mathematics and natural philosophy, let alone the so-called ‘scientific revolution’, is still far from settled. Harriot, who was both a gifted mathematician and a scrupulous experimenter, is a figure who will help us to continue thinking through these important questions.

**Future prospects**

So what remains to be done? Which areas of Harriot’s legacy have still to be fully explored? I’d like to begin this section of my talk with a snapshot of my own recent – as yet unpublished – work on a very particular aspect of Harriot’s work, his mechanics. The benefits of this are twofold. Firstly, it will show that there are unexplored aspects of topics which have already been well covered. Secondly, it emphasizes the fruitfulness of approaching the work of Harriot via his friends and colleagues, in this case the mathematician and natural philosopher, Walter Warner.

 Harriot’s small treatise on the collision of round bodies, the *De reflexione corporum rotundorum* was prepared in 1619 for his patron Henry Percy, ninth Earl of Northumberland from some ‘auntient ... notes’ on the topic.[[67]](#endnote-67) We know from a letter accompanying this treatise, that Harriot shared his ideas with both Warner, and another friend and member of the Percy household, Robert Hues:

Sir. When Mr Warner and Mr Hues were last at Syon, it happened that I was perfecting my auntient papers notes of the doctrin of reflections of bodies. Unto whom I imparted the magisteryes thereof, to the end to make your Lordship acquainted with them as occasion served.[[68]](#endnote-68)

Harriot’s writings on the collision of round bodies are well-known and have been closely studied by Jon Pepper, Martin Kalmar, and (most recently) by Russell Smith.[[69]](#endnote-69) However, a group of hitherto unknown manuscripts on collisions and motion written by Walter Warner provides us with new evidence that provides a new context for Harriot mechanics.[[70]](#endnote-70)

 In the Isham-Lamport papers in the Northamptonshire Record Office, a significant number of previously undiscovered Warner manuscripts were unearthed in the mid-1990s by Timothy J. Raylor: some 337 folios in 14 sewn notebooks or smaller manuscripts, distributed into six manuscript bundles. Amongst these are three sewn notebooks relating to what Warner refers to as ‘kinetica’ or the ‘doctrina de motu’. These are:

Notebook III: Fragments of a treatise on the collision of spherical and plane-sided bodies.

Notebook IV: A treatise labelled ‘De motu et quiete’

Notebook V: A set of notes headed ‘De corporum non resultantiam … effectis ex mutua incidentia oriundis’ [‘Effects arising from the mutual incidence of non-rebounding bodies’], including a number of theorems, definitions, consectaries, and problems concerning the collision of bodies.

These 39 folios – which can be dated to around 1601-1603 – give us a new insight into the study of mechanics in the Northumberland circle.

 Warner’s papers suggest a hitherto unacknowledged source for a key concept in Harriot’s work on collisions – *linea nutus*, the line of inclination, or line of force, which Martin Kalmar glosses as ‘the tendency that a body has to move in a given direction with a given speed’.[[71]](#endnote-71) Both Warner and Harriot use this term,[[72]](#endnote-72) and they both consider collision in terms of the composite of the weights and motions of the colliding bodies, represented by lines which designate ‘the forces or active powers of given bodies’.[[73]](#endnote-73) In his papers on rebounding and non-rebounding bodies, Warner describes the motion of two bodies ‘after the moment of impact’ (*post incidentiae ictum*) and the ‘new velocity’ (*velocitas nova*) or ‘secondary velocity’ (*velocitas secundaria*) acquired by the moved body.[[74]](#endnote-74) Harriot’s two porisms also talk of the ‘effect after the moment [of impact]’ (*effectus post ictum*) and the ‘nutus acquired from the moment [of impact]’ (*nutu ex ictu acquisito*), or ‘second motion’ (*motus secundus*) which is ‘a composite of two forces’ (*ex duobus nutibus compositus est*).[[75]](#endnote-75) While he recognized its importance, Kalmar was mistaken is in his assumption that ‘This use of *nutus* is … unique to [Harriot]’.[[76]](#endnote-76) As Jon Pepper has correctly noted, the *linea nutus* concept had a ‘respectable ancestry’, and he points out that the term can be found, for example, in Henri Monantheiul’s commentary on the Pseudo-Aristotelian *Quaestiones mechanicae* of 1599.[[77]](#endnote-77) But there is another, earlier, source for the term, and one which seems likely to have been the direct source for Monantheuil’s own usage, and that is the *Tractatus de motu*, the only published work of the Genevan lawyer Michel Varro (1542-1586).

 Varro has long been known to historians of science. As long ago as 1857, the English historian William Whewell recognized Varro’s work as ‘an anticipation of the doctrine of the Composition of forces’, while Alexandre Koyré mentions him in his *Études Galiléennes* as a pre-Galilean example of the principle of the proportionality of the velocity of a moving body in relation to distance, and Stillman Drake noted the close similarity between Varro’s line and triangle diagrams and those found in Galileo’s working papers.[[78]](#endnote-78) Despite these early signs of interest in Varro’s work, apart from an article by Serge Moscovici in 1958,[[79]](#endnote-79) little work was done on his treatise until Michele Camerota and Mario Otto Helbing’s edition and translation published in 2000.[[80]](#endnote-80) Camerota and Helbing present Varro’s work as ‘an important chapter in the history of late sixteenth-century mechanics’, and its author as an early precursor of the mathematical natural philosophy of Galileo.

It is not surprising that Pepper was unaware of Varro as a possible source for Harriot and Warner’s ideas in 1976 when Varro’s work was little known, and Warner’s papers on the topic had yet to be discovered. It is these new papers, in fact, which lead me to believe that Varro is the ‘missing link’ in Harriot’s theory. While Warner is not often given to citing the authors he makes use of, and seems to have preferred to make his own exhaustive dialectical considerations of questions rather than citing authorities, in the case of his writings on impacts and collisions we find not one, but two, distinct references to Michel Varro, the first of which links him specifically to the concept of *linea nutus*, when he mentions ‘the line of force (w[hi]ch Varro calleth linea nutus)’.[[81]](#endnote-81)

It is not merely a question of borrowing a single term, however. I would argue that Varro’s ideas on motion and force had a profound effect on the ways in which Harriot and Warner viewed and presented their findings on mechanics. The idea of the *linea nutus* as a way of geometrically representing the effects of force on bodies is central to Warner and Harriot’s theories. As Jon Pepper noted in his 1976 article: ‘The implicit principle [of Harriot’s theory of impacts] is one of the linearity of independent causes, or rather of their effects. The resolutions along the lines of centres, then, seems to be a fundamental part of the theory’.[[82]](#endnote-82) This is also the case with Warner’s definition and theorems, which take the ‘linearity’ of forces, and their tractability to geometrical analysis as their starting point.

Warner also explicitly acknowledges his reliance on Varro’s treatment of the relationship between motion, resistance, and weight. Thus, in what appears to be a note added to his papers entitled *De motu et quiete*, long after their original composition (perhaps after his discussions with Harriot and Hues in 1619), we find the following statement:

By motive power [*potentia motiua*] is understood the ratio of resistance as (according to Varro, as I remember) resistance is understood as the ratio of magnitude or stability of a moveable body, or rather of the support or both.[[83]](#endnote-83)

We also have a brief but suggestive piece of evidence which indicates that Harriot was reading Varro’s work. In a ‘Memorandum’ written sometime in the 1590s, when he was working on ballistic problems, Harriot listed a number of books including ‘Varro’, ‘My notes of ordinance’, and ‘Proclus de motu’.[[84]](#endnote-84) While it has been suggested that this was a reference to the Roman author Marcus Terentius Varro, whose extant works deal with agriculture and the history of the Latin language, given the context it seems almost certain that Harriot’s book-bag contained Michel Varro’s *De motu tractatus*.[[85]](#endnote-85) It would appear from this that Harriot’s interest in Varro began with his practical mathematical work on the motion of projectiles and falling bodies (because of Varro’s attention to the doctrine of motion in general) and subsequently stimulated his interest in the mechanics of colliding bodies.[[86]](#endnote-86)

 There are other areas of Harriot’s legacy that are in urgent need of reappraisal. One of the most obvious of these is Harriot’s optics. Although they have been the subject of a series of ground-breaking essays by Johannes Lohne between the late 1950s and the early 1970s, his optical papers still have much to offer historians of science:[[87]](#endnote-87) his work on refraction (including his often-noted anticipation of Snell’s law),[[88]](#endnote-88) chromatic dispersion, the location of images, and burning glasses. I do not intend to dwell on Harriot’s optics today, however, as I am aware that Robert Goulding, the Harriot lecturer in 2001 is currently working on a book, provisionally entitled *Images of broken light: experiment and mathematics in the search for a law of refraction 1597-1637*, which will include a detailed examination of Harriot’s experimental and mathematical work in this area: Harriot’s optics are in safe hands.[[89]](#endnote-89)

**[Figure 1 about here. Caption below, at end of main text]**

 Another area that I think would repay further attention is Harriot’s encounter with the great Italian mathematicians of the late sixteenth century, Federico Commandino and Guidobaldo del Monte. Just as Jacqueline Stedall revealed Harriot’s debt to Viète in his algebraic work, but also his innovations and independent discoveries, I think a close look at Harriot’s engagements with problems inherited from these Italian mathematicians would reveal a similar story. An example that would be well worth pursuing is the question of centres of gravity, a topic investigated both by Harriot and by Warner. It was clearly an area of mathematics that Harriot felt was important, as the inventory of his mathematical papers made by Sir Thomas Aylesbury after this death mentions three bundles of papers on the subject ‘De centro gravitatis’ (and is the second item of the inventory, immediately after his papers on algebra).[[90]](#endnote-90) The primary impetus here comes from Commandino’s *Libro de centro gravitatis solidorum*, published in 1565, which extolled the ‘very beautiful’ demonstrations of this ‘very obscure and very difficult question’, which – Commandino informed Cardinal Alessandro Farnese to whom the book is dedicated – offers ‘the greatest assistance in clearly understanding many things which are propounded in mathematics’.[[91]](#endnote-91) As we can see from Add. MS 6788, Harriot was working his way through the problems in Commandino’s book. On folio 262v, we can see him working on the centre of gravity of a section of a pyramid from p. 35 of Commandino’s treatise. However, Harriot is no passive disciple of the Italian mathematician, but a critical one. As we can see from the bottom of this page where he notes: ‘This proportion is more suitable, although Commandino did not notice it. Yet it is collected from the elements of his demonstration’ (see Figure 1).[[92]](#endnote-92) Having grasped the essence of the problem, Harriot is satisfied with Commandino’s solution, but presents it in what he thinks is a more elegant form. In another example, also taken from his work on Commandino’s book, he criticizes the Italian mathematician’s demonstration of a proposition which, he says, is presented ‘unclearly, and in another fashion’ than the one that Harriot has set down.[[93]](#endnote-93) Harriot’s attitude sometimes goes beyond criticism to emulation – in the sense of seeking to ambitiously surpass one’s rivals.[[94]](#endnote-94) Thus here we see Harriot having once again formulated a problem (concerning the centre of gravity of a parabolic section) differently from Commandino writing at the bottom of the page ‘Vale Comandine tu non habes magisteriu[m]’ – which we could render as ‘farewell Commandino, you don’t have the best solution’![[95]](#endnote-95) Harriot was also working on exactly the same problems – those concerning the centre of gravity of solids – in the *Liber mechanicorum* of Guidobaldo del Monte, published in 1588. But Harriot presents his demonstration in algebraic terms, whereas Guidobaldo restricts himself to a more traditional geometrical style,[[96]](#endnote-96) and when working through Guidobaldo’s demonstrations he presents alternative methods of his own.[[97]](#endnote-97)

 Another problem that taxed both Harriot and Warner was one taken from Commandino’s translation of the work of Pappus of Alexandria, the *Mathematicae collectiones*, also published in 1588.[[98]](#endnote-98) This is the section, or ‘resection’ of space (*De resectione spatii*), which had been handled by Pappus in two books. This involved the solution of a problem in which the geometer is given two straight lines and a point in each, and is required to draw a third line through a third given point so that the rectangle contained by the two intercepts are equal to a given rectangle.[[99]](#endnote-99) As Jacqueline Stedall noted in 2002, this is ‘a topic treated more than once by Harriot and found several times among Warner’s papers’, and an inventory of Warner’s papers made by Herbert Thorndike after Warner’s death includes an entry for a bundle of papers on this topic.[[100]](#endnote-100) In fact, we know that Warner and Harriot shared ideas on the topic as Warner made fair copies of Harriot’s solutions to some of these problems, marked ‘T.H.’ at the top left-hand corner.[[101]](#endnote-101) Harriot and Warner also worked on other problems from Pappus, including determinate sections, and tangents.[[102]](#endnote-102) A short manuscript treatise by Warner presenting ten problems in tangency can be found in the hand of Robert Payne in Chatsworth House.[[103]](#endnote-103)

 It is important that we try to piece together these engagements with Italian Renaissance mathematics, I think. Not simply in order to chart its reception in the English context – although that would not be without interest – but because we know that Harriot used these new mathematical tools when confronting physical questions which interested him. As I said earlier, Schemmel has shown how Harriot was able to use specific problems from Archimedes and Pappus when he was wrestling with the nature of the ballistic trajectory. A case in point can be found in a cryptic passage amongst his papers on centres of gravity in BL Add. MS 6788.[[104]](#endnote-104) (See Figure 2) We can see from this passage that centres of gravity are not mere abstractions for Harriot but concern real physical bodies and their behaviours. The diagram and the accompanying text suggest that the centre of gravity of any particular moving object is not in the object itself (which is ‘the subject of gravity’), but – following Aristotle – at the centre of the earth (‘centrum terrae’).[[105]](#endnote-105) How we interpret the other remarks here ‘In the descent of a sphere along a plane – whether it is revolved or not – motion is caused of necessity, but not the end [of motion]. Double contact’, is not immediately obvious, but it suggests that more careful attention to Harriot’s doctrines of motion and mechanics might be enhanced by a fuller understanding of these mathematical problems.[[106]](#endnote-106)

**[Figure 2 about here. Caption below, at end of main text]**

 A theme arising out of a study of the works of these Italian mathematicians, as well as the works of other continental mathematicians such as Simon Stevin and Marino Ghetaldi, which I raised in my first Harriot lecture, but which has still not been sufficiently exhausted, is the topic of hydrostatics, or statics more generally. Sir William Lower felt that Harriot had allowed Ghetaldi to beat him into print on the question of the Archimedean method of calculating specific gravities by weighing objects in water. This was certainly an area that interested both Harriot, and other members of the Northumberland household. Warner’s papers included a work on the statics of solid and fluid bodies, the *Ad praxim staticam elementa quaedam accomoda*,[[107]](#endnote-107) and Nathaniel Torporley wrote a brief critique of Simon Stevin’s *Hydrostatica*, ‘De pondere aquae’, at the request of Henry Percy, in which he defends several Archimedean propositions, and seeks to show that Stevin had fallen into a number of serious errors.[[108]](#endnote-108) It is interesting to note, by the way, that Torporley, like Harriot and Warner, makes use of the *linea nutus* concept in this work to explain water pressure.[[109]](#endnote-109) An assessment of Harriot’s specific gravity experiments, in the wider context of the engagement with statics and hydrostatics in the Northumberland would repay the effort, I suspect.[[110]](#endnote-110)

 Another area which could usefully be revisited is Harriot’s work on spirals and rhumb lines. Harriot’s colleague Robert Hues, in the preface of his *Tractatus de globis et eorum usu* in 1594 expected the imminent publication of Harriot’s thoughts on this subject:

We are awaiting a whole treatise on the generation, nature, and use of rhumbs by Thomas Harriot, who is most expert in mathematics and universal philosophy. In which many things concerning this argument have been subtly and acutely thought out, elaborated with great industry, refined with the utmost judgement, and weighed in the balance of mathematical demonstrations: which work we hope to see published very soon.[[111]](#endnote-111)

Hues had every right to be so expectant – Harriot had done a lot of work. In an inventory of his manuscripts made after his death, we find listed ‘A black box full of papers of Rhombes’.[[112]](#endnote-112) While we have the excellent and comprehensive article on Harriot’s work on rhumb lines and meridional parts by Jon V. Pepper,[[113]](#endnote-113) might it not be possible to reconstruct a treatise on this topic, beginning with those papers headed ‘De rumbis’ and ‘De helicis’, in HMC 240, II? Pepper published a selection of the most significant manuscript pages in his 1968 article, but he noted at the time that his transcriptions were ‘only a small selection of those available’.[[114]](#endnote-114) Anyone who wished to undertake this should begin with Pepper’s article as he has provided any future editor with a helpful calendar of the relevant folios they would need to piece together.[[115]](#endnote-115)

 Schemmel’s historical epistemological method strikes me as a very fruitful approach to follow in other areas than Harriot’s mechanics. Comparison with other mathematicians and natural philosophers in the late sixteenth and early seventeenth century and how they dealt with the same kinds of problems will help us to map out the problematic areas in which mathematics and natural philosophy overlap. Historians of astronomy, as Jim Bennett noted at the beginning of his 1995 lecture, ‘seem often to be disappointed by Thomas Harriot’.[[116]](#endnote-116) But what if we were to set him in a wider European context of astronomical observation? If we look at other comparable figures in Europe at Harriot’s time, such as Nicolas-Claude Fabri de Peiresc (1580-1637), what can we learn about observational practice? If we look, for example, at the famous astronomical observations made by Peiresc together with his friend Joseph Gaultier de la Vallette (1564-1647) on 24 November 1610. The two men – like Harriot – were observing the moons of Jupiter (which they refer to here as ‘the Medicean planets’ – *les Planètes Medicées*) when they became aware of ‘a certain little illuminated cloud composed of two stars’ in the middle of Orion,[[117]](#endnote-117) making them the first observers of the Orion nebula (now known as M42). Whilst this was a momentous discovery, what I find interesting here is the similarity of Peiresc’s observational practices to those of Harriot. Like Harriot, Peiresc frequently observed with others (in this case Gaultier), and like Harriot he recorded their shared doubts about what they had seen through the telescope. Peiresc names the four Galilean moons ‘Francisc[us]’, ‘Ferdin[andus]’, ‘Cosmi ma[ioris]’ and ‘Cosmi min[oris]’ after the four recent Medicean Grand Dukes of Tuscany.[[118]](#endnote-118) Peiresc records the varying levels of certainty about the appearance of these remote planetary bodies. At the top of the page under the date he writes ‘Monsieur Gaultier began to see the Medicean planets’ (‘M. Gaultier a com[m]ence à voir les Planetes Medicées’). Further down he writes ‘we began to see them ourselves in this way’ (‘Nous auons com[m]encé à les voir nousmemes En ceste sorte.’). He then notes the differing status of these observed bodies, there is no doubt about the first (‘de prima non ambigit[ur]’), the second was doubted very much (‘de 2a dubitatur valde’) although the third less so (‘de 3a minor est dubita[ti]o’). This use of multiple witnessing is typical of Harriot too, who often recorded his own doubts and those of his companions Christopher Tooke or Nicholas Sanders about particular observations.[[119]](#endnote-119) A more sustained comparison of the observational methods of Peiresc and Harriot could well prove fruitful.[[120]](#endnote-120) Cometography is another area where comparisons with broader trends would be instructive. Harriot made careful observations and measurements of both the 1607 and 1618 comets.[[121]](#endnote-121) Tracking down the observations of his contemporaries both in print and manuscript would allow Harriot’s work to feature as part of a broader investigation of the early seventeenth-century understanding of these astronomical phenomena.

 These are just a few suggestions for where future research on Harriot might be directed. Harriot scholarship is moving into a new and exciting phase. Much has already been accomplished, but much remains to be done. Thanks to the efforts of Jacqueline Stedall, Matthias Schemmel, and Robert Goulding, the dream of an edition of Harriot’s papers once cherished by John Shirley, David Quinn, and Cecily Tanner is becoming a reality. Although the transcriptions and commentaries are not yet complete, the process has started. Eventually a new generation of scholars will come to Harriot’s papers online, with expert commentary to guide them. I am sure that when these new scholars sift through these fascinating papers, they will find quite another Harriot than the one that I have found, a different Harriot from the one presented by Quinn and all the Harriot lecturers who came after him: they will find a Harriot waiting to be asked new, and as yet unasked questions.

**Acknowledgement**

All images from Add. MS 6788 in this article are taken from the ECHO Thomas Harriot Online website currently hosted by the Max Planck Institute, <http://echo.mpiwg-berlin.mpg.de/content/scientific\_revolution/harriot>. These images have been classified for use under the Creative Commons license.

**Captions**

**Figure 1**

Harriot, page of notes on Federico Commandino’s *De centro gravitatis solidorum* (1565). London, British Library, Additional MS 6788, fol. 262v

**Figure 2**

Harriot’s notes on the centre of gravity and the motion of a sphere along an inclined plane. London, British Library, Additional MS 6788, fol. 344v

**Notes**

1. J. W. Shirley (ed.), *Thomas Harriot. Renaissance scientist* (Oxford, 1974), viii. [↑](#endnote-ref-1)
2. D. T. Whiteside, ‘In search of Thomas Harriot’, *History of science*, 13 (1975), 61-70 (61). [↑](#endnote-ref-2)
3. Whiteside, ‘In search of Thomas Harriot’, 62. [↑](#endnote-ref-3)
4. Whiteside, ‘In search of Thomas Harriot’, 65. [↑](#endnote-ref-4)
5. J. A. Stedall, *A discourse concerning algebra. English algebra to 1685* (Oxford, 2002), 88. [↑](#endnote-ref-5)
6. Stedall, *English algebra*, 96. [↑](#endnote-ref-6)
7. Stedall, *English algebra*, 123. [↑](#endnote-ref-7)
8. J. A. Stedall, *The greate invention of algebra. Thomas Harriot’s treatise on equations* (Oxford, 2003). [↑](#endnote-ref-8)
9. Stedall, *English algebra*, 107-11, and Stedall, *Greate invention*, 22-26. [↑](#endnote-ref-9)
10. *Thomas Harriot’s Artis analyticae praxis. An English translation with commentary*, ed. M. Seltman and R. Goulding (New York, 2007). [↑](#endnote-ref-10)
11. See Stedall, *Greate invention*, Appendix, ‘Correlations between Harriot’s manuscripts and the texts of Vìète, Warner and Torporley’, 291-99, and Seltman and Goulding, *Artis analyticae praxis*, ‘Comparative table of equations solved’, 263-69, and ‘Commentary’, 209-62, *passim*. [↑](#endnote-ref-11)
12. Stedall, *Greate invention*, 5. [↑](#endnote-ref-12)
13. Ibid., 4-5, and fn. 6, 301 for Stedall’s dating of Torporley’s letter to Harriot at the time he met Viète. [↑](#endnote-ref-13)
14. Ibid., p. 6. Cf. Stedall, *English algebra*, 94. [↑](#endnote-ref-14)
15. Stedall, *Greate invention*, 14. [↑](#endnote-ref-15)
16. Stedall, *Greate invention*, 17; Stedall, *English algebra*, 96. [↑](#endnote-ref-16)
17. *Thomas Harriot’s doctrine of triangular numbers. The ‘Magisteria magna’*, ed. J. Beery and J. A. Stedall, Heritage of European Mathematics (Zurich, 2009). [↑](#endnote-ref-17)
18. Beery and Stedall, *Triangular numbers*, 3-4. [↑](#endnote-ref-18)
19. Beery and Stedall, *Triangular numbers*, 5 [↑](#endnote-ref-19)
20. Beery and Stedall, *Triangular numbers*, 9. [↑](#endnote-ref-20)
21. Beery and Stedall, *Triangular numbers*, 15, 17. [↑](#endnote-ref-21)
22. Beery and Stedall, *Triangular numbers*, 17. [↑](#endnote-ref-22)
23. Beery and Stedall, *Triangular numbers*, 19. [↑](#endnote-ref-23)
24. Beery and Stedall, *Triangular numbers*, 20. [↑](#endnote-ref-24)
25. Beery and Stedall, *Triangular numbers*, 20-47. [↑](#endnote-ref-25)
26. Beery and Stedall, *Triangular numbers*, 47-52. [↑](#endnote-ref-26)
27. M. Schemmel, *The English Galileo. Thomas Harriot’s work on motion as an example of preclassical mechanics*, 2 vols. (Dordrecht, 2008). [↑](#endnote-ref-27)
28. Schemmel, *English Galileo*, vol. 1, 4-5, 232. [↑](#endnote-ref-28)
29. Schemmel, *English Galileo*, vol. 1, 5. [↑](#endnote-ref-29)
30. Schemmel, *English Galileo*, vol. 1, 3-4. [↑](#endnote-ref-30)
31. Schemmel, *English Galileo*, vol. 1, 233. [↑](#endnote-ref-31)
32. Schemmel, *English Galileo*, vol. 1, 5. [↑](#endnote-ref-32)
33. Schemmel, *English Galileo*, vol. 1, 235. [↑](#endnote-ref-33)
34. Schemmel, *English Galileo*, vol. 1, 56. [↑](#endnote-ref-34)
35. Schemmel, *English Galileo*, vol. 1, 66. [↑](#endnote-ref-35)
36. Schemmel, *English Galileo*, vol. 1, 85-87. [↑](#endnote-ref-36)
37. Schemmel, *English Galileo*, vol. 1, 87. For Digges’s speculations about ballistic trajectories and geometrical curves, see Thomas Digges, *An arithmeticall military treatise, named Stratioticos* (London, 1579), ‘Of randons’, 186-89. [↑](#endnote-ref-37)
38. Schemmel, *English Galileo*, vol. 1, 113. [↑](#endnote-ref-38)
39. Schemmel, *English Galileo*, vol. 1, 19. [↑](#endnote-ref-39)
40. Schemmel, *English Galileo*, vol. 1, 27-9. [↑](#endnote-ref-40)
41. Schemmel, English Galileo, vol. 1, 161-64. [↑](#endnote-ref-41)
42. Schemmel, *English Galileo*, vol. 1, 175. [↑](#endnote-ref-42)
43. Schemmel, *English Galileo*, vol. 1, 136-41. [↑](#endnote-ref-43)
44. Schemmel, *English Galileo*, vol. 1, 187. [↑](#endnote-ref-44)
45. Schemmel, *English Galileo*, vol. 1, 207. [↑](#endnote-ref-45)
46. Schemmel, *English Galileo*, vol. 1, 225. [↑](#endnote-ref-46)
47. R. Fox (ed.) *Thomas Harriot. An Elizabethan man of science* (Aldershot and Burlington, VT, 2000); idem, *Thomas Harriot and his world. Mathematics, exploration, and natural philosophy in early modern England* (Farnham and Burlington, VT, 2012). [↑](#endnote-ref-47)
48. S. Johnston, ‘Making mathematical practice: gentlemen, practitioners and artisans in Elizabethan England, Ph.D. thesis (University of Cambridge, 1994). [↑](#endnote-ref-48)
49. E. G. R. Taylor, *The mathematical practitioners of Tudor and Stuart England* (Cambridge, 1967). [↑](#endnote-ref-49)
50. A similar approach is taken by Eric H. Ash in his *Power, knowledge, and expertise in Elizabethan England* (Baltimore, MD, 2004). [↑](#endnote-ref-50)
51. Fox (ed.), *Thomas Harriot and his world*, 200. [↑](#endnote-ref-51)
52. Fox (ed.), *Elizabethan man of science*, 139. [↑](#endnote-ref-52)
53. Ibid., 142. [↑](#endnote-ref-53)
54. Ibid., 139-41. [↑](#endnote-ref-54)
55. Ibid., 142. [↑](#endnote-ref-55)
56. Fox (ed.), *Thomas Harriot and his world*, 106-10. [↑](#endnote-ref-56)
57. Ibid, 92. [↑](#endnote-ref-57)
58. Ibid, 98-101. [↑](#endnote-ref-58)
59. Ibid, 110. [↑](#endnote-ref-59)
60. Ibid., 117-18. [↑](#endnote-ref-60)
61. Ibid, 130. [↑](#endnote-ref-61)
62. Ibid, 134, 136-37. [↑](#endnote-ref-62)
63. Ibid., 132. [↑](#endnote-ref-63)
64. Ibid., 32. [↑](#endnote-ref-64)
65. Ibid. 41-43. [↑](#endnote-ref-65)
66. Ibid., 43. [↑](#endnote-ref-66)
67. Petworth House Archive (hereafter PHA), HMC MS 241 VIa, fols. 23r-31r. [↑](#endnote-ref-67)
68. Thomas Harriot to Henry Percy, 13 June 1619, London, British Library (hereafter BL), Harleian MS 6002, fol. 21 r–v. This is a copy made by Charles Cavendish, who adds the following note: ‘Mr Harriot’s letter to my Lo: Northumberland: annexed to his treatise of Reflections: lent me to transcribe by Sir Th: Alesburie’. [↑](#endnote-ref-68)
69. J. V. Pepper, ‘Harriot’s manuscript on the theory of impacts’, *Annals of science*, 33 (1976), 131-51; M. Kalmar, ‘Thomas Harriot’s *De reflexione corporum rotundorum*: an early solution to the problem of impact’, *Archive for history of exact sciences*, 16 (1977), 201-30; R. Smith, ‘Optical reflections and mechanical rebound: the shift from analogy to axiomatization in the seventeenth century. Part 1’, *British* *journal for the history of science*, 41 (2008), 1-18, esp. 7-15. There is also a recent doctoral thesis which devotes part of a chapter to the *De reflexione*: S. J. Hyslop, ‘The mathematics of collision and the collision of mathematics in the 17th century’, Ph.D thesis (Indiana University, 2015); see Chapter 2, ‘First investigations: Harriot and Beeckman on collision’, 10-51. [↑](#endnote-ref-69)
70. What follows summarises some of the findings of my forthcoming article: ‘Thomas Harriot and Walter Warner on collisions: mechanics and natural philosophy in early seventeenth century England’. [↑](#endnote-ref-70)
71. Kalmar, ‘Problem of impact’, 204. For a seventeenth-century definition, see M. Mersenne, *Universae geometriae, mixtaeque mathematicae synopsis, et bini refractionum demonstratarum tractatus* (Paris, 1644), II. 3, p. 458: ‘Linea recta ab extremo semidiametro in diametrum perpendiculariter acta demonstrat qualis sit nutus; nam quo maior est semidiameter, eo maior est praedicata linea, praedictúsque nutus; linea enim recta ducta à termino, à quo mobile mouetur, vsque ad terminum, in quo quiescit, dicitur *linea nutus* [...]’. [↑](#endnote-ref-71)
72. It is also used by Nathaniel Torporley in his ‘De pondere aquae’, BL Add. MS 4458, fols. 4r-5r (fol . 4v). Torporley says that the *linea nutus* of the individual parts of a mass of water are parallel to one another (*Lineas vero nutus partiu[m] singulariu[m] esse parallelas*). [↑](#endnote-ref-72)
73. PHA, Leconsfield MS 241, VIa, fol. 24r. [↑](#endnote-ref-73)
74. W. Warner, ‘De corporum non resultantiam … effectis ex mutua incidentia oriundis’, Northamptonshire Record Office (hereafter NRO), Isham-Lamport MS 3422, V, fol. 1r. [↑](#endnote-ref-74)
75. PHA, Leconsfield MS 241, VIa, fols. 24-25 [↑](#endnote-ref-75)
76. Kalmar, ‘Problem of impact’, 204 and fn. 6. [↑](#endnote-ref-76)
77. Pepper, ‘Theory of impacts’, 138 and fn. 13. [↑](#endnote-ref-77)
78. W. Whewell, *History of the inductive sciences,* 2 vols (London, 1857), vol. 2, 8; A. Koyré, *Études Galiléennes* (Paris, 1966; reprint, 2001), 89, fn. 2; S. Drake, *History of free fall. Aristotle to Galileo* (Toronto, 1989), 3. [↑](#endnote-ref-78)
79. S. Moscovici, ‘Notes sur le “De motu tractatus” de Michel Varro’, *Revue d’histoire des sciences et de leurs applications*, 11 (1958), 108-29. [↑](#endnote-ref-79)
80. M. Varro,*De motu tractatus* (Geneva, 1584). See M. Camerota and M. O. Helbing, *All’alba della scienza galileiana. Michel Varro e il suo De motu tractatus. Un importante capitolo nella storia della meccanica di fine Cinquecento* (Cagliari, 2000). On Varro as the probable source for Monantheuil, see pp. 24-6. [↑](#endnote-ref-80)
81. W. Warner, NRO, Isham-Lamport MS 3422, III, fol. 7v: ‘the line of force (w[hi]ch Varro calleth linea nutus)’. [↑](#endnote-ref-81)
82. Pepper, ‘Theory of impacts’, 140. [↑](#endnote-ref-82)
83. W. Warner, *De motu et quiete*, NRO, Isham-Lamport MS 3422, Notebook IV, fol. 10r: ‘Potentia motiua intenditur vel remittitur, pro ratione resistentiae (quod Varronis vt memine vt) resistentia intenditur vel remittitur pro ratione magnitudinis aut stabilitatis corporis mobilis vel potius firmamenti vel vtriusq[ue].’ [↑](#endnote-ref-83)
84. BL Add. MS 6786, fol. 364v. This list is discussed by S. A. Walton, *Thomas Harriot’s ballistics*, Durham Thomas Harriot Seminar Occasional Papers, no. 30 (Durham, 1999), 19-21. Although Walton suggests in his paper that Harriot’s list refers to a work by the Roman author Marcus Trentino Varro, or is a misspelling of the name of the Swiss Jesuit Sebastian Verro (p. 20), it seems more likely, given the subject matter of the other books on the list, that he is in fact referring to Michel Varro. [↑](#endnote-ref-84)
85. For the suggestion that ‘Varro’ was Marcus Terentius Varro, see S. A. Walton, *Harriot’s ballistics*, 20. [↑](#endnote-ref-85)
86. On Harriot’s working on falling bodies, see Schemmel, *English Galileo*. Schemmel makes no mention of Michel Varro in this excellent study. [↑](#endnote-ref-86)
87. J. A. Lohne, ‘Thomas Harriott (1560-1621), the Tycho Brahe of optics’, *Centaurus*, 6 (1959), 113-21; ‘Regenbogen und Brechzahl’, *Sudhoffs Archiv*, 44 (1965), 41-415; idem, ‘Kepler und Harriot: Ihre wege zum Brechungsgesetz’, in K. Meyer, F. Krafft, and B. Sticker (eds), *Internationales Kepler-Symposien weil du Stadt, 1971:* *referate und diskussionen* (Hildesheim, 1973), 187-214. [↑](#endnote-ref-87)
88. See J. W. Shirley, ‘An early experimental determination of Snell’s law’, *American journal of physics,* 19 (1951), 507-8. [↑](#endnote-ref-88)
89. For a foretaste of Goulding’s forthcoming work see R. Goulding, ‘Thomas Harriot’s optics, between experiment and imagination: the case of Mr Bulkeley’s glass’, *Archive for history of exact sciences*, 68 (2014), 137-178. [↑](#endnote-ref-89)
90. BL Add. MS 6789, fol. 448r: ‘De Centro Gravitatis, 3 b[undles].’ [↑](#endnote-ref-90)
91. F. Commandino, *De centro gravitatis solidorum* (Bologna 1565), sig. +2r. Harriot was also interested in the work of the Jesuit Luca Valerio (1553–1618) on this topic. See Add. MS 6788, fol. 358r for a detailed recording of the title page of Valerio’s *De centro gravitatis solidorum libri tres* (Rome, 1604). On fol. 289r he refers to demonstrations from books 2 and 3 of this work. [↑](#endnote-ref-91)
92. BL Add. MS 6788, fol. 262v.: ‘Haec ratio est magis accommoda quam Comandinus obseruavit. Attamen ex elementis apud illu[m] colligitur.’ Cf. Commandino, *De centro gravitatis solidorum*, 35. [↑](#endnote-ref-92)
93. PHA, HMC MS 241 VIa, fol. 14r and 15r.: ‘comandinus de centr[o] grav[itatis] prop. 22, sed obscurè et alio modo’. [↑](#endnote-ref-93)
94. See, for example, his executive summary of ways to ascertain the centre of gravity in sections of triangles, parabolas, cones, and pyramids, which are ‘much easier to use’, Add. MS 6788, fol. 321r: ‘De centro grauitatis frustoru[m] eclogae aliter dispositae, vsui magis accomoda’. [↑](#endnote-ref-94)
95. BL Add. MS 6788, fol. 332v. Harriot repeats this formula on fol. 335v, where he gives his solution to the centre of gravity of a conic section. [↑](#endnote-ref-95)
96. See e.g., BL Add. MS 6788, fol. 267v: ‘De centro gravitatis Trapezij vt Archimedis. Guidus Vbaldus, pag. 108’. Cf. G. del Monte, *In duos Archimedis aequeponderantium libros paraphrasis* (Pesaro, 1588), 108. [↑](#endnote-ref-96)
97. See, e.g., Add. MS 6788, fol. 283r (‘Aliter. et nostro methodo’). [↑](#endnote-ref-97)
98. F. Commandino, *Pappi Alexandrini mathematicae collectiones à Federico Commandino Urbinate in latinum conversa, et commentariis illustrata* (Pesaro, 1588). [↑](#endnote-ref-98)
99. Commandino, *Mathematicae collectiones*, p. 158b: ‘Per datam punctum rectam lineam ducere secantem à duabus rectis lineis positione datis ad data puncta, lineas, quae spacium contineant dato spacio aequale.’ [↑](#endnote-ref-99)
100. Stedall, *English algebra*, 242, fn. 89. An example of Warner working on the resection problem is BL Add. MS 4396, fols. 40r-44r. [↑](#endnote-ref-100)
101. NRO, Isham-Lamport MS 3422, VI, fol. 12: ‘De resectione rationis’; fols. 18-22r: ‘De resectione spacij’. [↑](#endnote-ref-101)
102. Ibid., fols. 14-15: ‘De determinata sectione’ and fols. 4-6: ‘De determinata sectione’. [↑](#endnote-ref-102)
103. W. Warner, ‘De tactionibus’, Chatsworth House Archive, Hobbes MS B.5. See also another non-autograph copy of this short work in BL Harley MS 6755, fols. 3-14. [↑](#endnote-ref-103)
104. BL Add. MS 6788, fol. 344v. [↑](#endnote-ref-104)
105. ‘Centru[m] grauitatis no[n] in subiecto grauitatis. Motus necessariò causatur sed non determinatio in des[c]ensu sphaerae p[er] planu[m] an reuoluatur necne. Duplex contactus.’ [↑](#endnote-ref-105)
106. I suspect that Harriot is responding here to Hero of Alexandria’s discussion of a sphere rolling down an inclined plane in the *Mechanica*. See S. Roux and E. Festa, ‘The enigma of the inclined plane from Hero to Galileo’, in W. R. Laird and S. Roux (eds), *Mechanics and natural philosophy before the Scientific Revolution* (Dordrecht, 2008), 195-221. [↑](#endnote-ref-106)
107. BL Harley MS 6754, fols. 2-74, and NRO, Isham-Lamport MS 3422, I. [↑](#endnote-ref-107)
108. N. Torporley, ‘De pondere aquae quo premuntur ij quibus altius incumbit. Quaestio D[omi]no Henrico Comite Northumbriae proposita, et ventiliata’, BL Add. MS 4458, fols. 4r-5r [↑](#endnote-ref-108)
109. See note 72 above. [↑](#endnote-ref-109)
110. A recent contribution to our understanding of Harriot’s hydrostatics is provided in N. Biggs, ‘Thomas Harriot on the coinage of England’, *Archive for history of exact sciences*, 73 (2019), 361–83. See also S. Clucas, ‘“The curious ways to observe weight in water”: Thomas Harriot and his experiments on specific gravity’, *Early science and medicine*, 25 (2020), 302-27. [↑](#endnote-ref-110)
111. R. Hues, *Tractatus de globis et eorum vsu* (London, 1594), 111.: ‘De rumborum ortu, natura & vsu integrum tractatum expectamus à Thomas Harioto matheseos & vniuersae Philosophiae peritissimo. à quo in hoc argumento multa subtiliter & acutè excogitata, magnâ industriâ elaborata, summo iudicio expolita sunt, & ad Geometricarum demonstrationum trutinam perpensa: quem propediem edendum speramus’. See D. B. Quinn and J. W. Shirley, ‘A contemporary list of Harriot references’, *Renaissance quarterly*, 22 (1969), 9-25 (13-14). [↑](#endnote-ref-111)
112. BL Add. MS 6789, fol. 449r. [↑](#endnote-ref-112)
113. J. V. Pepper, ‘Harriot’s calculation of the meridional parts as logarithmic tangents,’ *Archive for history of exact sciences*, 4 (1968), 359-413. [↑](#endnote-ref-113)
114. Pepper, ‘Meridional parts’, 391. [↑](#endnote-ref-114)
115. Pepper, ‘Meridional parts’, 391-93. [↑](#endnote-ref-115)
116. Fox (ed.), *Elizabethan man of science*, 137. [↑](#endnote-ref-116)
117. N. C. Fabri de Peiresc, *Journal des observations*, Bibliothèque Inguimbertine, Carpentras,

France, MS 1803, fol. 189 r: ‘In Orione media ... ex duabus stellis composita nubecula[m] quamdam illuminat[am].’ For a recent transcription of the relevant manuscript see H. Siebert ‘De Peirescs Nebel im Sternbild Orion - eine neue Textgrundlage für die Geschichte von M42’, *Annals of Science*, 66:2 (2009), 231-246 (239). See also H. Siebert, ‘Die Entdeckung des Orionnebels. Historische Aufzeichnungen aus dem Jahr 1610 neu gesichtet’, *Sterne und Weltraum*,11 (2010), 32–42, and S. L. Chapin, ‘The astronomical activities of Nicolas Claude Fabri de Peiresc’, *Isis,* 48 (1957), 13-29 (19). Harriot’s ‘first obseruation ... of the newfound planets about Iupiter’ was dated 17 October 1610. PHA, HMC MS 241 IV, fol. 3r. [↑](#endnote-ref-117)
118. Cosimo I de’ Medici (d. 1574), Francesco de’ Medici (d. 1587), Ferdinando de’ Medici (d. 1609) and Cosimo II de’Medici (d. 1621). I would like to thank Prof. Dr Harald Sibert for his advice regarding Peiresc’s observations. [↑](#endnote-ref-118)
119. See, e.g., PHA, HMC 241 IX, fol. 3r (9 April 1611, lunar observations with Tooke and Sanders); PHA, HMC 241 VIII, fol. 10r. (26 January 1611/12, sunspot observations with Tooke). [↑](#endnote-ref-119)
120. Although Harriot’s and Galileo’s maps and drawings of the moon have been much discussed, as far as I know, Peiresc’s moon drawings have not been discussed in this context. On Harriot and Galileo, see T. F. Bloom, ‘Borrowed perceptions: Harriot’s maps of the Moon’, *Journal for the history of astronomy*, 9 (1978), 117-22; H. Bredekamp, ‘Gazing hands and blind spots: Galileo as draftsman’, in J. Renn (ed.), *Galileo in context* (Cambridge, 2001), 153-92, esp. 176-84; S. Pumfrey, ‘Harriot’s maps of the Moon: new interpretations’, *Notes and records of the Royal Society*, 63 (2009), 163-68; A. Chapman, ‘A new perceived reality: Thomas Harriot’s Moon maps’, *Astronomy & geophysics*, 50 (2009), 1.27–1.33. [↑](#endnote-ref-120)
121. See PHA, HMC MS 241 VII, fols. 1-39. [↑](#endnote-ref-121)