Thomas Harriot and His World: Mathematics, Exploration, and Natural Philosophy in Early Modern England edited by Robert Fox

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Thomas Harriot is an enticing figure for many historians of science. He seems to have done everything and did these things (novel insights in the theory of equations, optics, ballistics, and astronomy to name a few) well before those who achieved recognition for their discoveries. He trained men in navigation, was on board on voyages of exploration, and took part in establishing an English colony in the New World. He made a lexicon of Algonquian and published one of the earliest accounts of America in English. He watched his patron, Ralegh, be executed and performed experiments with his next patron, Henry Percy, the Earl of Northumberland, in the Tower of London, where Percy was imprisoned. He appears in the poetry of his friend George Chapman and seems to have associated with the same people as Christopher Marlowe. Harriot lived a fascinating life. He entices because he is intrinsically interesting and brilliant. But there is more that has drawn the historian to Harriot.

Harriot is an underdog. Although his mathematics was excellent and novel, although he discovered the sine law of refraction before Descartes and Snell, although he observed the Moon through a telescope prior to Galileo, although he worked through significant problems in mechanics, he gained almost no recognition. He was largely forgotten and for many centuries assumed to be rather insignificant. Harriot excites a desire among some historians to restore honorably and dutifully his reputation—to give his works 'the recognition they deserve'. This characterizes aspects of Jon V. Pepper's chapter in *Thomas Harriot and His World*, 'Thomas Harriot and the Great Mathematical Tradition' [11–26], as well as the chapter by Jacqueline Stedall.

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Harriot is a puzzle. The historian finds in his manuscripts algebraic symbols, numbers, and diagrams, with little continuous prose.[1] Harriot inspires historians motivated by puzzles to piece together an intricate and difficult jigsaw as seen, for example, in Jacqueline Stedall's chapter, 'Reconstructing Thomas Harriot's Treatise on Equations' [53–64].[2]

Harriot seems to invite speculation. Since there is relatively little prose in his manuscripts and since he famously published very little, Harriot's ideas are not always apparent. Harriot's unpublished documents take the form of many tantalizing pieces. Some historians have produced compelling narratives and have attempted to provide meaning and coherence to the traces and fragments, e.g., Robert Goulding in his chapter, '*Chymicorum in morem*: Refraction, Matter Theory, and Secrecy in the Harriot-Kepler Correspondence' [27–51].[3]

Harriot is also a locus of reform. Harriot prompts other historians to challenge the many and sometimes entrenched speculative narratives and inferences that have been drawn, which they see as unlicensed stories that have unnecessarily and falsely embellished an individual whose work can stand on its own. Harriot's extensive manuscripts have proven to be an area for historians to uncover carefully what they may see as the 'real Harriot' or at least to state confidently that there is not enough evidence to know this or that claim that has been made. This theme can be found in John Henry's chapter, 'Why Thomas Harriot Was *Not* the English Galileo' [113–137] as well as in Ian Maclean's 'Harriot on Combinations' [65–87].[4]

1 The Harriot manuscripts from the British Library have been put online through the Max Planck Institute for the History of Science and European Cultural Heritage Online (ECHO): http://echo.mpiwg-berlin.mpg.de/content/scientific_revolution/harriot. As Fox notes in his introductory essay [3], contributors Jacqueline Stedall and Matthias Schemmel are planning a digital edition of all of Harriot's manuscripts.

2 I have borrowed the puzzle metaphor from Stedall, who explains that

> [engaging with the history of mathematics] is like trying to fit together a very large jigsaw in which most of the pieces are missing and one is not allowed to look at the picture on the box. One always hopes, of course, that some new and vital piece will turn up, but one knows all too well that it may not. [53]

3 Some past examples include Gatti 2000, Rukeyser 1970, and Yates 1936.

4 See also, for example, Clucas 2000.

The status and reputation of Harriot is a compelling *explanandum* that defies a strict intellectual history. Harriot's work seems to have been just as good if not better than the best of his contemporaries; and yet Harriot's status was minor and, until fairly recently, he was largely forgotten. This invites the social historian of science to explain why Harriot was not recognized and why he was not as influential as his contemporaries. A great many of the chapters take up this issue in some form but Stephen Pumfrey takes it on in a novel and sustained manner in 'Patronizing, Publishing and Perishing: Harriot's Lost Opportunities and His Lost Work "Arcticon"' [139–163].

Thomas Harriot, Renaissance man, explored many worlds and provides topics of interest to a variety of historians of early modern science. He is an enduring figure in the modern study of the history of science, who has proved to be irresistible to a great many. Some devote the majority of their waking lives to him;[5] others happily call themselves 'Harrioteers' and, as the dedication of Fox's edited volume [v] indicates, many see themselves not as specialists in a historical figure but as themselves students of Harriot.

Thomas Harriot and His World: Mathematics, Exploration, and Natural Philosophy in Early Modern England is the latest compilation of Thomas Harriot Lectures given from 2001–2009 at Oriel College, Oxford. The first set of lectures dating from 1990 has been published as *Thomas Harriot: An Elizabethan Man of Science*, which is also edited by Fox [2000]. Oriel is a fitting location since Harriot himself spent time at St Mary Hall, which is now part of Oriel, earning a BA in 1580. Modern historians of science have been meeting in Oxford since at least 1967 under the promotion of such scholars as David Quinn, Alistair Crombie, John North, and John Roche, to discuss their shared interest in Harriot. In 1977, Dr R. C. H. [Cecily] Tanner financed a biennial meeting in Durham chaired by Gordon Batho which continues to meet to the present as the Thomas Harriot Seminar (THS). The volumes produced from the Thomas Harriot Lectures, together with the publications

5 As Shirley remarks:

> It has been more than thirty-five years since I began seriously to study Thomas Harriot. ...[T]his fascinating man has occupied a large portion of my waking thoughts during this period. Following his elusive genius has taken me to most of the places that Harriot himself visited during his sixty years.... [1983, v]

arising from the Thomas Harriot Seminars,[6] are joined by the previous, *Thomas Harriot: Renaissance Scientist* [Shirley 1974]. This volume is composed of papers presented at the Thomas Harriot Symposium organized by John Shirley and held at the University of Delaware in April 1971.

In the late 1940s, Shirley gained access to a significant set of Harriot's manuscripts which had been kept at Petworth House after the majority of them had been sent to the British Museum as a gift around 1810 [1983, 20].[7] With the succession of John Edward Reginald Wyndham as Sixth Baron Leconfield, and First Baron Egremont in 1967, the Petworth collection was opened further to Harriot scholars. This tradition has continued and expanded with his son, (John) Max Scawen Wyndham, the current Lord Egremont and Leconfield, who provides financial support for the Harriot Lectures and to whom *Thomas Harriot and His World* is dedicated.

The chapters in *Thomas Harriot and His World* were written over nine years by historians from several different countries and scholarly backgrounds. Nevertheless, there are several themes running throughout the volume. In his eloquent introduction, Fox has summarized the chapters and tied them together as 'The Many Worlds of Thomas Harriot' [1–10]. In this review, we will focus on the discussions of Harriot's mathematics, its possible influence, and its worth as a window into the shared knowledge of the time. The notion of mathematics as a style of thinking and occupation will be reviewed as well as the distinctions between mathematics and natural philosophy. We will briefly survey the persisting disagreements regarding whether Harriot had a natural philosophy. In addition to mathematics and natural philosophy, we find a more complex and robust portrait of Harriot's character presented by various chapters. This will inform a discussion of the perennial topic of Harriot's lack of publications and subsequent status and culpability.

Jon V. Pepper has been studying Harriot's mathematics and science at least since his PhD thesis on the topic in 1979. In his contribution to *Thomas Harriot and His World*, Pepper focuses on the mathematical work of Harriot in a way that is self-consciously independent of the social context of Harriot's

6 http://www.bbk.ac.uk/english/our-research/research_seminars/thomas-harriot-seminar/ths-publications.

7 Harriot's manuscripts have had a colorful history: see Shirley 1983, 1–33.

time and place [11].[8] In Pepper's assessment, '[Harriot] belongs to the great tradition of mathematicians' alongside the likes of 'Eudoxus…Viète, Newton, Gauss, Maxwell, [and] Poincaré' [25]. This is due to the virtues of Harriot's work itself, namely, that

> he applied not only the existing mathematics of his time to various problems …but also created new ideas, new notations, techniques and theories. [25]

To illustrate this claim, Pepper dedicates the majority of his chapter to summarizing several examples of Harriot's mathematical work and notes previous scholarly studies that have examined his work more thoroughly. In addition to some of the more well known discoveries of Harriot,[9] Pepper devotes several pages to discussing in some detail Harriot's work 'rectifying' the plane equiangular spiral and the twisted loxodromic spiral, in other words, Harriot's efforts to find the exact length of these curves. This is notable since, as Pepper indicates, 'no-one before Harriot had found the exact length of any curve' [17] and since Descartes after him thought such lines did not have determinable length at all but were 'beyond human knowledge' [16].

In addition to Pepper's evaluation that Harriot should belong to the 'great tradition of mathematicians' based on the independent merits of Harriot's mathematical work, Pepper makes another claim regarding the *influence* of Harriot in the larger trends of the history of mathematics:

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[8] Chapter 1, 'Thomas Harriot and the Great Mathematical Tradition', was originally presented as the 2000 Thomas Harriot Lecture.

[9] Pepper notes Harriot's discoveries in algebra, particularly his work developing *methods* (such as the interpolation and area methods) to solve problems expressed in 'algebraic symbolisms' [14]. He discusses Harriot's discovery of the sine law of refraction (prior to both Descartes and Snell) and his applications of it to 'questions of dispersion and the height of the primary rainbow' [13, 15]. He briefly covers Harriot's work on the theory of impacts, his work as a calculator, his work in navigation and astronomy, and his work in calculating 'the extended meridian lines necessary to construct a Mercator mapping' [16]. He mentions that because of Harriot's use of the binary decomposition of integers to help calculate exponentials, Harriot 'forms part of a continuing chain' extending from 'Ah'med (Rind Papyrus c. 1650 BCE) to modern computer work' [23]. And he notes that Harriot applied 'quite sophisticated mathematics' to shipbuilding and design, and ends by mentioning that Harriot correctly described parabolic trajectories in ballistics which he obtained by 'combining uniform motion with orthogonal uniform acceleration, one of Galileo's best-known results (1638)', although this was done, of course, independently of Galileo [25].

> If we have to look in general terms, what is most notable...is his contribution to the move away from geometrical to algebraic formulations. This move is often regarded as an eighteenth-century development, but it was in fact a late sixteenth-century development, first by Viète and then by Harriot, and it has been the dominant movement of the four centuries since that time. [25]

This is an intriguing claim and may well be true. However, it is unsupported in the chapter. Pepper provides no account of how Harriot's algebraic work may have been influential in the larger movements of mathematics, particularly since, in his own words, he does not discuss the 'intellectual ambience or climate of [Harriot's] place and times' [11]. He also does not provide an account of the possible ways in which the mathematical work in Harriot's manuscripts may have had any impact at all. Harriot was proficient and original in his work in algebra, as Pepper's chapter makes clear. But, since Harriot famously did not publish—which Pepper himself notes and attempts to explain—and since much of his reputation was based on a posthumous publication that did not present his work as favorably as it may have (*Artis analyticae praxis*, 1631), an explanation is needed for how Harriot *contributed* to the movement of mathematics rather than independently working in relative isolation in areas that may have become characteristic of broad trends.

This lacuna is filled, at least partially, by Jacqueline Stedall. She notes in her contribution[10] that publishing mathematical works was actually 'the exception rather than the rule' in England in the first half of the 17th century [61], a point that is supported by Stephen Pumfrey's arguments[11] from the studies of patronage included in the volume, which will be discussed more below. For Stedall,

> Mathematical ideas were exchanged freely amongst...[those] who were interested in them by means of letters, manuscripts and conversations. There is evidence that Harriot's manuscripts remained in circulation for up to 30 years after his death. [61]

[10] Chapter 3, 'Reconstructing Thomas Harriot's Treatise on Equations' was originally presented as the 2002 Harriot Lecture as 'The Greate Invention of Algebra: Thomas Harriot's Treatise on Equations'.

[11] See Pumfrey's argument in chapter 7 [139–164] as well as his argument in Pumfrey 2003, which Henry has conveniently summarized in chapter 6 [115–117].

She cites Beery and Stedall 2009 for an argument that Harriot's ideas persisted by 'word of mouth' and catalogues later mathematicians in England such as Walter Warner, Thomas Alesbury, John Pell, Charles Cavendish, and the Savilian Professor of Geometry at Oxford, John Wallis, who all knew of and appreciated Harriot's work on algebra.

However, Stedall's purpose is not to argue the extent to which Harriot was responsible for a shift away from geometric to algebraic formulations. Instead she documents the existence of a significant 'Treatise on Equations' written by Harriot, inspired by Viète's *De numerosa potestatum resolutione*, but scattered through Harriot's manuscripts. Although the manuscripts were divided between the British Library and Petworth House, Stedall has reassembled the treatise which contains '[Harriot's] reworking in his own notation of Viète's *De resolutione*', and which goes beyond Viète to include his own method of solving quadratic equations by factorization, an idea of 'profound significance because it enables mathematicians not just to solve equations but also to look inside their structure', and utilized a method of comparison with 'canonical equations' [56]. This treatise, uncovered and reassembled by Stedall, is more thoroughly argued for and examined in a publication subsequent to her Harriot Lecture in 2002 [see Stedall 2003].

Like Pepper, Stedall is an open advocate of Harriot's reputation as a great mathematician: as she writes,

> In attempting to restore Harriot's original 'Treatise on equations', I see myself as but the latest in a long line of people who have hoped that Harriot and his algebra would eventually get the recognition they deserve. In the seventeenth century alone, William Lower, Nathaniel Torperley, Thomas Aylesbury, Walter Warner, John Pell and John Wallis all tried to see justice done to Harriot and his mathematics. [63–64]

Much of Harriot's reputation has been based on the posthumous publication known as *Artis analyticae praxis* (1631), which was put together from manuscripts, likely by Harriot's friend Walter Warner, although Harriot had named Nathaniel Torperley in his will to oversee and publish his mathematical writings. According to Stedall, the *Praxis* was 'in many ways a travesty of [Harriot's] original intentions' [60]. Relying on corroborating evidence from an unfinished manuscript by Torperley entitled 'corrector analyticus', which was in his own words, 'An Analytic Correction of the Posthumous Work of

Thomas Harriot', Stedall argues that Harriot's original intentions consist of a document much like the 'Treatise on Equations' that she has restored.

Even if it was the case—contrary to Pepper and Stedall—that Harriot effectively had no influence in the main developments of what would become modern science, the particulars of his work are still important to understand. Whereas Pepper examined the worth of Harriot's ideas in abstraction and Stedall has both reconstructed his ideas and indicated that they were championed by his peers and some of his immediate successors, Matthias Schemmel has taken quite a different approach.[12] Rather than imply that the force of Harriot's good ideas must have provided a 'link in the chain', and rather than claim that Harriot was nonetheless influential contrary to what one might think due to his lack of publications, Schemmel is interested in Harriot for the very fact that he was not influential, at least when compared with someone like Galileo. Here is why: Schemmel emphasizes that 'the thinking of an individual is governed to a large degree by knowledge that is shared with his or her contemporaries, or certain specialized groups of contemporaries' [90]. A study of a rather obscure individual's work on motion, for example, and a comparison of it with Galileo's work on motion could provide insight into this 'shared knowledge' of early modern mechanics—the loose set of ideas stemming from a variety of sources and experiences such as Aristotelian physics, techniques of medieval calculation, and the 'practical knowledge of engineers and gunners' [90]—which interested individuals would have had available to them in beginning to think about motion.[13]

Schemmel has since extended this argument and provided a 'comprehensive reconstruction, analysis and interpretation of Harriot's work on motion' [90] in *The English Galileo: Thomas Harriot's Work on Motion as an Example of Preclassical Mechanics* [2008]. In doing so, Schemmel manages to provide an excellent intellectual history of Harriot's and Galileo's similar studies of projectile trajectories, while providing a means to tackle much larger questions regarding the nature of scientific development such as 'To what extent do the peculiarities of an individual scientist's work influence its outcome?' and 'Do the peculiarities of an individual scientist's work lead to diverging develop-

12 Chapter 5, 'Thomas Harriot as an English Galileo: The Force of Shared Knowledge in Early Modern Mechanics' was originally presented as the 2004 Harriot Lecture.

13 Schemmel uses the term 'pre-classical mechanics' to refer to this loose collection of ideas and practices. In doing so, he self consciously follows Damerow *et al.* 2004.

ments in science? Would we have a completely different physics today had there been no Galileo? Or do alternative developments converge?' [91] At least in the case of Harriot and Galileo, whose 'inferential pathways' proceeded in opposite directions from each other, evidence suggests the latter.

Several of the other contributions also take up the topic of mathematics; but rather than engage with the mathematics itself, they address it in terms of a style of thinking, a title, or as an occupational category distinct from others such as natural philosophy. Perhaps because Harriot's achievements have been sung so strongly, some scholars now find it necessary to explain why, despite 'all of his astonishing genius' [115], Harriot did not rise to the level of Galileo, Kepler, or Descartes. Henry, in his contribution,[14] notes a tradition of frustration among Harriot scholars who want to champion his reputation, lament his lack of recognition, and wish that he had fully articulated a philosophy of nature [125].[15] Henry argues that what makes Harriot distinct from the reputable Galileo and thus not an 'English Galileo' so to speak, is that Galileo was a mathematician who strove also to be a natural philosopher. Not only did Galileo achieve both titles, he transformed natural philosophy into something new in the process, combining speculative philosophy with mathematics and experimentation. Harriot, on the other hand, was an excellent mathematician but he never endeavored to be a natural philosopher or, as Henry would put it, he *refused* to be one [125].

According to Henry, Harriot was essentially a mathematician and approached the world intellectually as a mathematician. He did not seek natural explanation with causal narratives as a natural philosopher would. Instead, he measured and reported and solved problems: and Henry claims that there is little evidence that Harriot ever speculated or drew conclusions from these activities [128]. To support this view, Henry points to Harriot's pictures of the Moon, noting the lack of explanation or speculation, and contrasts this with Galileo's *Sidereus nuncius* (1610), which draws conclusions from Galileo's pictures of the Moon. For instance, the Moon is not a perfect sphere—the patterns seen on the Moon through the telescope are not just patterns to be drawn and recorded but are to be understood as mountains and craters. According to Henry, it is likely that 'Harriot would still have seen mathematics

[14] Chapter 6, 'Why Thomas Harriot Was *Not* the English Galileo' was originally presented as the 2005 Harriot Lecture.

[15] Particularly, he cites Shirley 1983, North 1974, Gatti 2000, and Jacquot 1974.

and natural philosophy as separate and distinct enterprises' [134]. He likely respected this separation and 'was always thinking as a mathematician' [128].

An important plausible exception to Henry's thesis is Harriot's alleged matter theory, specifically his variety of atomism, which has been discussed at length by modern historians of science since at least 1966 with the publication of Robert Kargon's *Atomism in England from Harriot to Newton*.[16] However, there is not agreement among historians on the particulars of his theory or if it is even appropriate to say that Harriot had a theory.[17] (This will be discussed more at length below.) Henry cites some of the evidence that scholars have typically drawn on to argue that Harriot was an atomist: Torperley's criticism of Harriot for being an atomist and a reference to the topic in Harriot's correspondence with Kepler. But in response, Henry attempts to provide a deflationary account. He claims that it may have been nothing more than a debate between friends (Harriot and Torperley) or, if it was something more, Harriot's position was so weak that Henry finds it 'hard to believe that Harriot could have had much confidence in his own position' and, more generally, that 'it seems hard to imagine that he could have developed confidence in natural philosophizing by drawing upon atomism' [130, 131]. Despite Henry's excellent point regarding the differences between Galileo the natural philosopher and Harriot the mathematician, this argument is fairly unsatisfying. Even if it is true that Harriot's atomism was unpolished and did not rise beyond a debate between friends, this does not exclude it from being an example of natural philosophizing. Moreover, the claim that Harriot must have lacked confidence in his ideas simply because they are, in the assessment of the historian, weak is quite tenuous. And anyway, bad natural philosophizing would still be an example of philosophizing. Henry goes on to compare Harriot to Descartes, who brought together geometrical optics, an account of colliding bodies, and 'a matter theory that was closely modeled on atomism', and concludes that he was not an 'English

[16] Kargon's discussion of Harriot has been repeatedly criticized. For example, see Clucas 2000, 102–103 and Bennett 2000, 139–140.

[17] A nice overview of Harriot's place on the 'field of knowledge' according to several historians of science can be found in Stephen Clucas' contribution to the previous volume of Harriot Lectures [2000], particularly pages 94–106. Elsewhere, Henry has questioned whether Harriot should even be identified as an atomist [1982, 2010]. On the other hand, Hillary Gatti [2000] has argued that Harriot did have a natural philosophy which included a form of atomism.

Descartes'. This too, if true, only establishes that Harriot was different than Descartes. It says nothing about the existence of Harriot's efforts in 'natural philosophy'. Henry argues against the *hypothetical* position claiming that, since Harriot also studied optics, colliding bodies, and atomism, he must have been 'involved (before Descartes!) in trying to develop a new system of mechanical philosophy' [131]. But Henry cites no one who has supported this position. And more importantly, this is a different argument from one about whether Harriot pursued any form of natural philosophy to some extent.

Robert Goulding is also interested in the mathematical and natural philosophical occupations of Harriot and uses the above-mentioned correspondence with Kepler to draw some very different conclusions than does Henry. For instance, Goulding claims that Harriot was confident about his ideas based in atomism—so confident in their importance in fact that he felt it necessary to protect these ideas from being 'robd' by taking on the *persona* not of a mathematician but an alchemist. As a great many of the contributors to this volume note, even Harriot's contemporaries wished that Harriot had published his ideas and thought that he was continually being robbed of his inventions and glories when others published or presented ideas that he had discovered first. At least four of the contributors to the volume quote from the same passage from a letter that William Lower wrote to Harriot in 1610:[18]

> Do you not here startle, to see every day some of your inventions taken from you ...and yet to[o] great reservednesse had robd you of these glories...Onlie let this remember you, that it is possible by too much procrastination to be prevented in the honor of some of your rarest inventions and speculations. Let your Countrie and friends injoye the comforts they would have in the true and great honor you would purchase your selfe by publishing some of your choise workes. [Shirley 1983, 1–2, 400]

Through a close reading of Harriot's correspondence with Kepler, Goulding infers that Harriot tried, unsuccessfully, at least once, to inform the wider world about one of his 'inventions', namely, his results regarding refraction, understood according to a corpuscularian account of matter and light. By his reading of the letters, Goulding claims that Harriot wanted to stake his claim to superiority against his main rival in optics, Kepler, who at the time thought there was some 'mathematical regularity' to refraction but did not

[18] Goulding, Stedall, Henry, and Pumfrey all quote various portions of this passage (some more than what I have here reproduced).

yet have it [35]. Harriot wanted to do so without revealing his hand and thus without having yet another of his 'inventions taken'.[19] To accomplish this, responding to language used by Kepler to describe him, Harriot portrayed himself as 'a mysterious "initiate of nature"...revealing his discoveries only to shroud them in deeper obscurity' [39]. In response, a frustrated Kepler, '[who] saw himself as a model of openness' [38] wrote to Harriot that he was acting *chymicorum in morem*, which Goulding translates as 'just like an alchemist'. This, Goulding claims, was not only a mere *persona* that Harriot deliberately donned as a strategy, since alchemy was also an important part of Harriot's intellectual activity.

It may be the case that Harriot was motivated to attain recognition for this result and took on the *persona* of an alchemist to protect it. Goulding's explanation fits together quite nicely and he is very familiar with the source material. However, attributing motivations to individuals who lived 400 years ago on fairly sparse evidence is challenging. Such a motivation might explain why Harriot wrote in the obfuscating manner that he did to Kepler, but it also seems plausible that Harriot may not have been driven to seek any recognition at all. After all, as Goulding acknowledges, this would be the only outstanding case where Harriot might have sought recognition. Perhaps Harriot was satisfied in the roles made possible for him by his patron and was not interested in seeking personal recognition.[20] Nevertheless, Goulding's account is compelling.

Henry acknowledges that historians have wanted to attribute a natural philosophy to Harriot but he draws a sharp distinction between natural philosophy and mathematics, and argues that Harriot was interested strictly in the latter. Goulding, on the other hand, assumes that Harriot had a natural philosophy in which his optics, his account of collision, and his atomism were all a

[19] Goulding writes,

> Perhaps [Harriot] concluded that if he were to reveal his results 'freely and frankly', as Kepler exhorted him, he would surely see yet another one of his 'choise works' claimed as the invention of another. [39]

[20] See Pumfrey's argument regarding patronly manuscript culture *versus* commercial print culture [139–164], and the brief comments on the topic by Pepper [12] and Stedall [61].

part of it.[21] He then argues that Harriot was acting like an alchemist on purpose and that 'his study of refraction really was closely connected to his studies and experiments in alchemy' [29]. Optics, atomism, and alchemy are drawn into an intelligible whole to shed light on the correspondence with Kepler, which in turn reinforces the links that Goulding has made. What Henry argues to be separate and to bear no evidence of natural philosophy, Goulding assumes to be a natural philosophy. This dual tendency to infer the existence of a natural philosophy and to deny that Harriot had one is fairly longstanding and only one of many areas of disagreement about how to place Harriot in the 'field of knowledge', a topic addressed explicitly in several of the Harriot Lectures collected in the previous volume, *Thomas Harriot, An Elizabethan Man of Science* [Fox 2000].[22]

Ian Maclean also weighs in on the topic of natural philosophy in his contribution to the present volume.[23] Maclean is primarily concerned with the extent to which Harriot's combinatorial ideas were influenced by the 'social, political and religious context' (he claims that they were scarcely influenced at all by context), and the extent to which Harriot was marked by a 'scientific' or 'occult' mentality. But he is also interested in the relationship between natural philosophy (specifically, its connection to the contemplation of the godhead) and mathematics. He concludes that Harriot 'was capable of compartmentalizing his mind and of according different modes and degrees of commitment to different areas of his mental universe' [87].

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21 According to Goulding, Harriot's optics was based in a theory of the structure of matter. Since light is partially reflected and partially refracted by some materials, Harriot concluded that matter is particulate. If matter was structured as a regular array of atoms, when light hits it, some would be deflected and some would enter and pass through the spaces between the atoms, deflecting off each atom in a zigzag fashion. Although the zigzag path would be too small to see, the overall path of light through the array of atoms would be visible, which accounts for refracted light. Although Harriot does not explicitly express this theory in his writings, Goulding infers it from the critical writings of Harriot's friend and sometime critic, Torperley, as well as the diagrams in Harriot's manuscripts and Harriot's initially perplexing comments to Kepler which when interpreted in this light become more intelligible.

22 See Bennett 2000, Clucas 2000, Gatti 2000, and North 2000.

23 Chapter 4, 'Harriot on Combinations' was presented as 'Thomas Harriot on Combinations' as the 2003 Harriot Lecture.

Several of the contributions to the present volume, as well as past works, have noted Harriot's propensity for mathematics as well as for what appears in the manuscripts to be a preference to record, measure, and calculate, with relatively little speculation or explanation. This has been interpreted in a variety of ways. On one extreme, it is claimed that he was strictly a mathematician who was uninterested in natural philosophy and refused to participate in it. On the other, it has been claimed that although he did not always write out his thoughts, there is enough evidence to reconstruct what his natural philosophical positions likely were. Judging by this volume, the disagreements regarding Harriot's natural philosophy remain unresolved. The chapters of reworked lectures here provide a more robust and complex portrait of Harriot's character. In addition to a mathematical style of thinking and a mind apparently capable of compartmentalization, we find what appears to have been a streak of competitiveness, as seen in Harriot's interaction with Kepler in Goulding's chapter.

Pascal Brioist presents Harriot meticulously observing, recording, ordering, and learning the practices and technical language of the officers and crew on board transatlantic voyages.[24] Harriot comes across as curious, a man with a 'special capacity to absorb all sorts of practical knowledge', who was inventive in his ability to 'imagine original solutions', and who clearly had what Brioist calls a 'restless intelligence' [200].

In the rare cases where Harriot did write in Latin, for example, in the explanatory notes to the engravings in the de Bry Latin edition of Harriot's *A Briefe and True Report* (Harriot's account of America and his only publication), it is the assessment of Charles Fantazzi that Harriot wrote in fluent, elegant humanistic Latin [232]. Harriot's Latin also 'demonstrate[s] his familiarity with the classical authors' [236].[25]

In Mark Nicholls' fascinating biographic portrait of Sir Walter Ralegh's life in three acts with special attention on the 'final act' (his trial and execution) and its place in the public's imagination, we find a Harriot who is 'no fair-

[24] Chapter 9, 'Thomas Harriot and the Mariner's Culture: On Board a Transatlantic Ship in 1585', was presented as 'Thomas Harriot and the Worlds of Practice: Learning from Seamen and Soldiers' as the 2009 Harriot Lecture.

[25] Charles Fantazzi develops this argument in his contribution 'Harriot's Latin', which appears as appendix B.

weather friend', a Harriot who is congenial, 'extremely sociable', and loyal to the end [175].[26]

In the assessment of many, Harriot's status suffered because he did not publish. It is commonplace to claim that if Harriot had published his various works, they inevitably would have had an enormous impact on the development of mathematics and science. As Stephen Pumfrey notes [141], for 400 years people have been asking this same question, 'Why did Harriot not publish and secure his reputation?' As we have seen in the much quoted letter from Harriot's friend Sir William Lower in February 1610, Lower seems to imply that Harriot may have been 'prevented in the honor of some of [his] rarest inventions and speculations' simply because of 'to[o] much procrastination'. In the current volume, Goulding fastens on this alleged personal foible and elaborates: Harriot may have been prevented from publishing by 'excessive caution' and 'insecurity'. Relying on evidence from Harriot's will, Goulding claims that if Harriot had intended to publish his works during his lifetime, 'even the task of discovering which were of any significance was, it seems, beyond him' [28]. This is essentially the received view. Pumfrey calls it the 'traditional and obvious explanation', namely, that 'Harriot was simply incapable of bringing…[his works]…to the level of completion that he desired and printers demanded' [155].

Jon V. Pepper modifies the received view by presenting six reasons for Harriot's 'non-publication', all of which lift much of the responsibility from Harriot. Pepper claims they are 'easy to see' but acknowledges that they are 'only conjecture'.

(1) Since Harriot had a generous patron, publication was less important.
(2) Some of his work was of a 'restricted' nature, 'classified' so to speak, and specifically not to be shared with others.[27]
(3) Printing the notations that Harriot developed would have been troublesome.
(4) Printers may have been sceptical that there would be an audience which could understand his mathematical works.

[26] Chapter 8, 'Last Act? 1618 and the Shaping of Sir Walter Ralegh's Reputation', was presented as the 2008 Harriot Lecture.

[27] Pepper's first two explanations, although only conjectures on his part, are corroborated by Pumfrey's argument as we will see.

(5) At times Harriot suffered from ill-health and was generally an extremely busy person, and
(6) due to his supposed unorthodox religious views, he may have feared attracting controversy [12].

Stephen Pumfrey turns the 400-year-old question around, which also, and even more so than Pepper's explanations, removes 'blame' from Harriot.[28] As we have seen, Henry, while responding to historians' frustration that Harriot was not clearer about his natural philosophy, has joined others in claiming that this frustration is at least in part the historian's fault: we should stop projecting our desire to find a natural philosophy in Harriot.[29] In a similar way, Pumfrey suggests that historians should stop projecting our norms of publication onto Harriot. Rather than ask why Harriot did *not* publish, we should ask why *should* he have published at all [143]. Pumfrey situates this new question in the context of his studies of early modern patronage. He notes that Harriot's life spanned a time of transition from the circulation of ideas in a private patronly manuscript culture to the circulation of ideas in a public commercial print culture. Through this change, the manuscript culture remained significant—the gift of a manuscript was individual and intimate and did not have the 'ungentlemanly' connotation of the personal pursuit of fame. A similar shift was also occurring between the notion of private 'secrets of nature' offered to one's patron to the notion of 'science' offered to the international public.[30] Pumfrey claims that

> historians of science have overlooked the extent to which Harriot was content with manuscript circulation, and the obstacles that prevented moving his work from manuscript culture to print culture. [143]

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[28] Chapter 7, 'Patronizing, Publishing and Perishing: Harriot's Lost Opportunities and His Lost Work "Arcticon"' was presented as 'Patronage, Protection, and Publication of Scientists in the Renaissance: The Strange Case of Thomas Harriot' as the 2006 Harriot Lecture.

[29] Henry quotes both chapters by Bennett and Clucas in the previous collection of Harriot lectures [Fox 2000].

[30] Pumfrey cites Eamon 1994, which has further developed this notion.

To illustrate this point Pumfrey contrasts the case of Harriot's lost work on navigation known as the 'Arcticon', which was never published,[31] with Harriot's contemporary Edward Wright's *Certaine errors in navigation*, which was printed in London in 1599. According to Pumfrey's well argued chapter, the publication of Wright's *Certaine Errors* was the exception and Harriot's 'Arcticon' was the norm.[32]

The evidence that Pumfrey uses to defend this position is quite interesting. He has studied the conventions of printing at the beginning of the 17th century and has found, after reading the front matter of more than 1000 early modern English specialist books, that the dedicatory letters follow a regular formula. From this, he has drawn several conclusions which support his theses.

(1) 'The specialist works were routinely first produced and circulated for a manuscript culture' [146].

(2) A printed work was only one of several that the author had composed, 'and that if the patron and readers approve, there are more and better books to come' [147].

(3) The patron played a 'crucial role...in authorizing a book to move fully into the public sphere as a printed edition' [149]. The patron had 'rights over its use and distribution', especially 'when the work conferred a clear advantage, for example, in military or economic terms'. And,

> the authority of a book, especially an innovative one, was established by the letter of dedication which made clear the involvement of a patron, whose supposed honour and discernment provided the Renaissance equivalent of the authority conferred today by a peer-reviewed academic journal. [149]

So for instance, Harriot's patron, Ralegh, may not have supported publication of Harriot's works on navigation because, if these results were made public, Ralegh may have lost his competitive edge in

[31] J. J. Roche has claimed that if it had been published 'it would have had an immediate impact on western navigation and established Harriot internationally as a navigation expert' [139] (quoted in Pumfrey's chapter).

[32] This point is also supported, although not explained, in Stedall's chapter:

> it must be borne in mind that in the first half of the seventeenth century, mathematical publication in England was the exception rather than the rule. [61]

some of his pursuits. Also, Ralegh dramatically fell from grace just as did Harriot's second patron, Henry Percy, who ended up imprisoned in the Tower of London. Consequently, neither had 'viable honour to lend to Harriot and his work' [149]; and yet, as we have seen in Nicholls' comments in his biographic portrait of Ralegh, Harriot remained loyal.

(4) Although they had stylized, formulaic references to critics, the critics mentioned in the dedicatory letters were not always mere tropes but sometimes in fact quite serious. Pumfrey has made a close analysis of the various kinds of criticisms that were acknowledged and combated in the dedicatory letters, as well as a particular analysis of Wright's situation. He finds that because of accusations of plagiarism (to which many texts were vulnerable since 'many works circulated for years in manuscript form' [153]), Wright was *forced* to publish to clear his name as well as that of his patron. Wright, in this difficult situation, unlike Harriot, had the honorable reputation of the Earl of Cumberland to 'authorize' his text.

Thus, there were few reasons why Harriot should have published: he may well have been comfortable in the patronly manuscript culture. But even if he had wanted to publish, there were several obstacles in his way due to the political situation of his patrons. In the case of Wright, there were exceptional reasons, stemming from accusations of plagiarism, that compelled him to publish and he had the support of a reputable patron to do so.

Fox's *Thomas Harriot and His World* continues to develop a more complete and nuanced portrait of Harriot's manner of thinking and of the quality of his work, particularly in mathematics. The contributions to this volume also demonstrate that the further examination of Harriot sheds light on many other aspects of early modern science, perhaps because Harriot thrived in so many diverse worlds. By learning more about Harriot, one comes to understand the importance of systems of patronage for the communication of ideas in a time of transition between manuscript and print culture in England. The study of Harriot provides insight into the 'shared knowledge' of the mechanics of motion at the time as well as into the social and intellectual importance of occupational divisions between natural philosophy, mathematics, and alchemy. A close look at Harriot reveals a keen 'outsider's' perspective on the vast technical and practical knowledge required of men on transatlantic voyages of exploration. Fox's volume also continues the tradition of striving for comprehensiveness in scope. Multiple methods are employed by an international cast of scholars spanning a decade of work in the history of science. And the tradition of keeping an up-to-date and extensive bibliography of works published on Harriot, which one finds in Shirley's edited volume [1974, 166–174] and updated by Katherine D. Watson in Fox's previous edited volume [2000, 298–303], is continued in this volume [243–247] by Daniel Jon Mitchell.[33]

In addition, three appendices are included,[34] the last of which follows up in a fascinating way on an appendix to the previous volume, which discussed several possible painted portraits of Harriot [Batho 2000]. A portrait of an unknown man hangs in the President's Room of Trinity College, Oxford, which is possibly that of Harriot. Diccon Swan has painted a copy of this portrait, which now hangs in the Hall of Oriel College, and has included his description [238–241] for Fox's current volume.[35] Swan explains that the painting is fairly modest and ends his piece, which also closes the volume, writing:

> Copying it was a fascinating job and, since it probably took me 10 times longer to copy than it took the artist to paint, I feel I probably know the painting better now than the artist himself ever did. [241]

The textual historical portrait of Harriot produced by the contributors to *Thomas Harriot and His World* no doubt also surpasses the original painted portrait hanging at Trinity College in talent, time, and care.

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33 As Mitchell notes, the website of the Thomas Harriot Seminar contains an up-to-date bibliography of publications on Thomas Harriot, which is maintained by Stephen Clucas.

34 'Appendix A: The 'Perfect' Harriot/de Bry: Cautionary Notes on Identifying an Authentic Copy of the de Bry Edition of Thomas Harriot's *A Briefe and True Report* (1590)' [201–229]; 'Appendix B: Harriot's Latin' [231–236]; and 'Appendix C: The Portrait of Thomas Harriot' [239–241].

35 The account was reproduced from the *Oriel College Record* [2007].

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