SPREADING THE WORD: PRACTICES OF DISCIPLESHIP IN EARLY MODERN NATURAL PHILOSOPHY

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Abstract

The publication of *De Revolutionibus Orbium Coelestium* by Nicholas Copernicus in 1543 exerted major intellectual and disciplinary effects on the field of astronomy. By promoting a heliocentric view of the world, and not merely offering a series of technical improvements to cosmology, Copernicus also affirmed the need for scholars to have mathematical expertise in that part of astronomy that dealt with the physical reality of the heavens. "Mathematics is written for mathematicians" (*Mathemata mathematicis scribuntur*) became a rallying cry for later Copernicans, which recognized in this claim a sort of Pythagorean heritage. Indeed, in the preface of *De Revolutionibus*, Copernicus had unequivocally depicted himself as a staunch Pythagorean, declaring his original unwillingness to publish his work to avoid the comments of the "babblers" – or the unlearned.

This work examines the institutional impact of Copernicus's demand for technical expertise. As numerous scholars have shown, his statement was effectively a plea for astronomers to speak authoritatively in areas that had previously been the preserve of natural philosophers. However, I argue, it also inaugurated a new template for the relationship between master and disciple, a structure that would constitute the foundations underpinning the successful transmission of varieties of the "new philosophy". As Copernicus claimed, it was only on the insistence of his disciple, the young mathematician Georg Joachim Rheticus, that he agreed to publish his work. The doctrine was recondite, difficult to acquire in its detail, and because of its unorthodoxy, easily misunderstood by any but the select few.

The case of Copernicus represents the starting point of my doctoral research. In the decades following the publication of *De Revolutionibus*, novel discipleship practices became essential to the development and spread of what became known generically as the "new philosophy". In this context, my work explores the fundamental role that the emergence of post-Copernican discipleship relations played in the achievements of the great new *auctores* Johannes Kepler, Galileo Galilei, and Isaac Newton. The analysis of these four cases offers a kaleidoscopic view of the evolution of the master-disciple relationship in astronomy and natural philosophy from 1530 to 1720, and highlights how different social, religious, and political contexts shaped this process both inside and outside the university.

INTRODUCTION

During the second half of the 18th century, in the preface of the two-volume work *Species Plantarum* (1753), the Swedish botanist Carl Linnaeus introduced the term "disciple" (*lärjungar* in Swedish) to indicate a group of students who carried out botanical and zoological expeditions throughout the world at the behest of their master. To Linnaeus, the word "disciple" – or apostle – had a very specific meaning: he saw himself as someone who had not only reformed but revolutionized the entire science of botany, and by perceiving this revolution in explicitly religious terms he thought that his travelling students or disciples were apostles in the most literal sense. Indeed, the "Linnaeus apostles" – as the group of seventeen students came to be known – were instrumental to his own scientific work: on the one hand, they spread the gospel of Linnaeus's new botanical principles throughout Europe; on the other hand, by collecting plant materials in other parts of the world they contributed to the empirical basis of his new system.[1]

The religious metaphor used by Linnaeus to denote his band of closest students provides precious information about the nature of the relationship between a master and his acolytes during the 18th century; also, it informs us that at the time discipleship became an accredited practice in the process of making and transmitting scientific knowledge. Even the Republic of Letters gave importance to its tradition: at the beginning of the century, the scholarly biography made mention of the master as an obligatory information.[2] In the previous centuries, the establishment of master-disciple relationships already constituted an essential means to pass on scientific knowledge; this practice, however, was neither institutionalized nor regulated by specific and uniform procedures. Several reasons contributed to this occurrence; the emergence of an increasingly mathematicised natural philosophy in the early modern period and the consequent reformation of the pedagogical system in the European Continent transformed both in practices and purposes the nature of this kind

[1] L. Hansen, (ed.), *The Linnaeus Apostles – Global Science & Adventure* (London; Whitby: The IK Foundation & Company, 2007–2012).
[2] M. Lilienthal, *De historia literaria certae cujusdam gentis scribenda consultatio* (Leipzig et Rostock: J. Henr. Russworm, 1710), pp. 119-120.

of relationship. Understanding such transformation is crucial not only to provide a systematic study on this topic but also to throw light on the connection between people and events that gave birth to modern science.

With this purpose in mind, the present work intends to investigate the fundamental role that, explicitly following the model of Pythagoras's relationship with his own disciples, the emergence of post-Copernican discipleship relations played in the achievements of the great new *auctores* Johannes Kepler, Galileo Galilei, and Isaac Newton. On the one hand, I will show how the evolving structures governing master-disciple relations in the fields of astronomy and natural philosophy drew from and built on existing structures in different institutions (the church, the university, schools of fine arts) and disciplines (theology, natural philosophy, mathematics). On the other hand, I will address a series of questions: how did a master of technical natural philosophy select his most talented tyros, and what was the nature of their apprenticeship? Why, in turn, did disciples seek to learn at the feet of specific masters, and what was expected of them when they had earned the trust of the expert? What, beyond the faithful development and dissemination of their master's ideas, and the ability to offer authoritative exegeses of their master's canonical works, made them trustworthy?

To address these questions, I will employ a wide cross-section of materials and methodologies. Firstly, in a world where the development of discipleship attachments often needed recourse to long-distance correspondence, the exchange of letters between masters and disciples will constitute an important source for determining the main traits of their interaction. Accordingly, I will pay close attention to the changing language of intimate affection and allegiance between master and disciple, much of which was indebted to religious and classical exemplars. Secondly, I will examine paratextual evidence such as marginal annotations in mathematical books along with personal notes and memoranda, all of which shed light on social and technical aspects of the interaction between the disciple and his master. Thirdly, the analysis of manuscripts and drafts will provide useful material for understanding the role of disciples in disseminating scientific knowledge

through both scribal and printed publications. My analysis of four case studies – Copernicus, Kepler, Galileo, and Newton – will offer a kaleidoscopic view of the evolution of the master-disciple relationship in astronomy, mathematics, and natural philosophy from 1530 to 1720, and will highlight how different social, religious, and political contexts shaped this process both inside and outside the university.

The Pythagorean sect

The conceptual doctrines and stipulations about the philosophical life promoted by Pythagoras and his followers represent the starting point of this investigation. The Greek philosopher was one of the most inspiring examples for early modern thinkers not only in relation to his mathematical achievements but also with regard to practices and customs that contributed to increasing his legendary fascination. According to the early biographies surviving from late antiquity, during his own lifetime Pythagoras was already considered a divine figure. The following historiography, moreover, enriched this picture with suggestive myths, anecdotes, and tales; his divine aura, combined with the intriguing philosophy that inspired the most renowned ancient thinkers like Plato and Aristotle, increased his reputation.[3]

The Renaissance *corpus* of writers who proclaimed themselves indebted to Pythagoras is extensive.[4] It comprehends manuscripts from the Late Middle Ages to the early Renaissance – Cusano, Ficino, Reuchlin; hermetic tomes belonging to the magic tradition of the 15th and 16th centuries – Agrippa, John Dee; and a range of writers in natural philosophy, notably the increasing number of Copernicans. The fascinating world that the Greek thinker built around his religious, philosophical, and mathematical principles engaged the attention of many intellectuals that aimed at both recovering the Pythagorean tradition and supplementing it with original elements from their

[3] P. Garnsey, "Pythagoras, Plato and communality: a note", *Hermathena*, No. 179, 2005, pp. 77-87.
[4] I. Caiazzo, C. Macris, A. Robert (eds.), *Brill's Companion to the Reception of Pythagoras and Pythagoreanism in the Middle Ages and the Renaissance* (Leiden; Boston: Brill, 2022).

own philosophies.[5] The great publishing endeavours facilitated by the emergence of print culture triggered the widespread circulation of the Pythagorean doctrine, ironically generating the opposite result to that Pythagoras himself had tried to pursue in his own time. Controlling – and limiting – the transmission of his mathematical achievements, indeed, was essential to his creed: it required the creation of a sect of trusted acolytes who were chosen, trained, and initiated into the practices of silence and secrecy, before becoming part of the limited audience that was allowed to receive the master's teaching. This sort of discipleship, thus, had not only the purpose of creating acolytes around a certain doctrine; it was also a subtle means to create a "private" teaching addressed only to selected, learned proselytes.

Mathematics represented the primary tenet of the Pythagorean doctrine. The Greek philosopher, indeed, considered numbers as the ultimate constituents of reality. In *Metaphysics* 1-5 Aristotle wrote: "The so-called Pythagoreans, who were the first to take up mathematics, not only advanced this subject but saturated with it, they fancied that the principles of mathematics were the principles of all things".[6] Indeed, Pythagoras believed that mathematics was essential to solve the great riddles of the universe and constituted the path toward enlightenment and understanding. Thus, while becoming the preferred means by which the world could be grasped and understood, mathematics also turned into a precious treasure to cultivate and protect. Why should mathematics be protected? The answer to this question resides in the Pythagorean consideration of mathematics as a superior branch of knowledge, a fact that gives us the sense and measure of how this discipline had acquired a moral significance connected to the notion of worthiness: mathematics was a divine experience, unfit for public eyes and about to be a full-blown religion of sacred mysteries. Such a primacy legitimated its authority and, consequently, its teaching became a privilege reserved for the few. Moreover, mathematics being the only way to understand the world, those few people also

[5] Joost-Gaugier, L. Christiane (eds), *Pythagoras and Renaissance Europe: Finding Heaven* (Cambridge, 2009). D. O'Meara, *Pythagoras Revived: Mathematics and Philosophy in Late Antiquity* (Oxford, 1989). C. S. Celenza, "Pythagoras in the Renaissance: The Case of Marsilio Ficino", *Renaissance Quarterly*, Vol. 52, 3, 1999, pp. 667– 711.
[6] Aristotle, *Metaphysics* (Indianapolis; Cambridge: Hackett Publishing Company, 2016), translated by C. D. C. Reeve, 1-5, p. 11.

became the only initiates allowed to have the key for opening the secret trove of nature, the custodians of pure knowledge and of its mysteries.

The organization of the Pythagorean school as reported by Iamblichus, Porphyry, and most of the ancient sources seems to corroborate this perspective. We do not know whether the information drawn by these authors is entirely reliable: since some biographers were enthusiast admirers, it is possible that most of what we have on Pythagoras is largely clouded by legend, mystification, and obfuscation. Nevertheless, when combined with other documents, these accounts offer interesting insights that concur in delineating an authentic portrait of the mysterious 'sectarians' that surrounded Pythagoras.[7]

According to the Hellenistic narration, the students attending the Pythagorean school were divided into two main groups: the novices were called *akousmatikoi* (or "listeners"); the advanced students were called *mathematikoi* (or "learners"). While the former could not look at the master while he was teaching and had to attend outside a curtained space, the latter could meet Pythagoras in person and know the secrets of the best-grounded *mathémata,* which were kept hidden from the rest of the world. In other terms, the *mathematikoi* were Pythagoras's closest and most trusted disciples, the truly privileged members of the Pythagorean sect. Such a privilege required a heavy price and involved a thorny initiation that lasted up to five years. For example, In his *Lives of the Eminent Philosophers*, Diogenes Laërtius reported that a five-year trial period was required to become initiated members of Pythagoras's household: for five whole years his pupils "had to keep silence, merely listening to his discourses without seeing him, until they passed an examination, and thenceforward they were admitted to his house and allowed to see him."[8] After a careful selection process based on physical, moral, and intellectual criteria, the tyros were trained to assimilate the

[7] L. Zhmud, "The Pythagorean Communities", in K. Windle, R. Ireland (eds), *Pythagoras and the Early Pythagoreans* (Oxford, 2012), pp. 135-168. M. J. Edwards, "Two Images of Pythagoras: Iamblichus and Porphyry", in H. J. Blumenthal and E. G. Clark (eds.), *The Divine Iamblichus: Philosopher and Man of the Gods* (Bristol Classical Press: London, 1993), pp. 159-72.

[8] D. Laërtius, *Lives of the Eminent Philosophers* (Harvard University Press, 1925), with an English translation by R. D. Hicks, vol. II, p. 331.

main regulations of the sect. Among these regulations, great attention was dedicated to the vow of silence, which was propaedeutic to the secrecy required both to protect mathematics from the unworthy non-initiated and to exercise self-control – a feature that any disciple who joined the cult learned to master and strengthen.

Silence, Pythagoras believed, was the cornerstone to his philosophy. All the surviving Hellenistic biographies mention that the Greek philosopher was initiated into the practice of silence by Egyptian priests together with Hebrew, Arab, and Chaldean sacerdotal ministries. The emphasis on the Egyptian tradition is very interesting and suggests that the Hellenistic biographers intended to establish a tacit relationship between Pythagoras and the cult of Harpocrates (Horus in the Egyptian tradition), the god of silence, secrets, and confidentiality.[9] Pythagoras as an erstwhile disciple of Egyptian ministers could not miss the importance of Horus, whose statues, erected inside every temple's courtyard, represented a naked boy apparently pressing a finger on his lips. This was the hidden message in the Hellenistic tale of Pythagoras visiting Egypt; the tradition that they established by connecting the Greek philosopher's doctrine and Harpocrates's vow of silence lasted for centuries and was significantly revived at the dawn of the modern age.[10]

All the ancient sources agree that the members of the Pythagorean sect were close-knit in complying with Pythagoras's strict regulations. There was only one exception who became the object of interesting and revealing tales; this was Hippasus of Metapontum, credited with the discovery of the existence of irrational numbers, who is often referred to as the first and only

[9] The Hellenistic god Harpocrates derived from the Egyptian god Horus, son of Iris and Osiris. On this identification – sometimes debated – see G. Parrinder, *A Dictionary of Non-Christian Religions*, (Hulton Educational Publications, 1971), p. 116-117; P. Turner, C.R. Coulter, *Dictionary of Ancient Deities*, (Oxford: Oxford University Press, 2001), p. 205. On the long tradition connecting Harpocrates, silence, and secrecy see: U. Eco, *Sulle spalle di giganti* (Milano: La nave di Teseo, 2017), pp. 320-355.

[10] Harpocrates's myth was frequently mentioned by 17th-century philosophers like Francis Bacon (*De Sapientia Veterum*, 1609), Gilbert Cuper (*Harpocrates*, 1676), and Ralph Cudworth (*The true intellectual system of the universe*, 1617-1688). Cudworth had great importance on Isaac Newton's education in this sense. In annotating one of Cudworth's manuscripts, Newton wrote: "The Egyptians besides their sphinges had also Harpocrates & Sigalions in their Temples with were statues of young men pressing their lips with their finger. p 316 vizt to signify that the young schollars of the wise should first learn silence, as Pythagoras taught his schollars". See "Out of Cudworth", Ms. fN563Z, William Andrews Clark Memorial Library, Los Angeles, California, USA (Accessed in Newton Project on 25th February 2018).

violator of the secrecy required on Pythagoras's mathematical discoveries.[11] For such an offence, he was sentenced to death and drowned at sea. This tale was never overlooked by the Hellenistic narrators, a fact that reinforced how much devotion was required to be a disciple of Pythagoras. Hippasus was a negative model, a *memento* to make clear that the requirements of silence and secrecy were more sacred than life itself. A letter written by the Pythagorean Lysis and addressed to Hippasus corroborates and supports this reading of the event:

> After the death of Pythagoras, I could not believe that the ties between his pupils would be broken. Though against all expectation we were, as if by a shipwreck, cut adrift and dispersed hither and yon, *it remains our sacred duty to remember the divine teaching of our master and not to divulge the treasures of philosophy to those who have not undergone preliminary purification of the mind*. For it is not proper to divulge to all and sundry what we have acquired with such great effort, just as it is not permitted to let ordinary men into the sacred mysteries of the elysian goddesses […] Let us remember how long it took us to purify our minds of their strains until, after five years had run their course, we became receptive to his teaching […] Some of his imitators achieve many and great things, but in the improper way and not the way in which youth should be taught; thus their audience is encouraged to ruthlessness and insolence, for they stain the pure tenets of philosophy with rash and impure demeanour. *It is as if one were to pour clean, fresh water into a well filled with dirt – for the dirt will only get agitated, and the water will be wasted*. This is what happens to those who teach and are taught in this manner. Thick and dark forests cover the minds and hearts of those who have not been initiated in the proper manner, and disturb the mild contemplation of ideas… *Many tell me that you teach philosophy in public, which was forbidden by Pythagoras* […] If you mend your ways I shall love you, if not, you are dead in my eyes.[12]

By intertwining mythological elements with historical facts of great relevance, the Hellenistic narratives contributed to defining a model that had a significant echo among thinkers and philosophers from late antiquity to early modern and beyond. Lysis's letter to Hippasus was well-known throughout the Greek world and circulated widely also in the following centuries, becoming the manifesto of the Pythagorean obligation of preserving mathematics from ordinary people unable to understand its real value.

Besides the central role that the Pythagorean philosophy has traditionally played as a precursor of heliocentrism – a theme which has been widely studied in the historiography[13] -- it is important to stress the relevance of Pythagoras's legacy in early modern mathematics and natural

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11 K. Von Fritz, "The Discovery of Incommensurability by Hippasus of Metapontum", *Annals of Mathematics*, Vol. 46, No. 2 (Apr., 1945), pp. 242-264.

12 Quoted by L. Prowe, *Nicolaus Copernicus*, (Berlin, 1883-4), vol II, pp. 132-137. (Emphasis added).

13 See T. Kuhn, *The Copernican Revolution* (Cambridge, Mass., Harvard University Press, 1957), pp. 42, 86, 116.

philosophy. Firstly, it promoted a peculiar way of conceiving mathematics as essential for understanding the very nature of the world and, more importantly, it was unusual in its insistence on the creation of a closed and elite group of acolytes to protect such precious knowledge from the unlearned. Pythagoras's model of discipleship became a template to acknowledge and reinterpret over the centuries. Starting from Plato, many intellectuals followed his example and cultivated circles of trusted and devoted acolytes that developed and expanded the master's teachings. But what happened to this process when the print revolution and the flourishing of academies and journals throughout Europe signalled a significant change in the way of communicating scientific achievements? How did early modern natural philosophers combine the Pythagorean requirement to restrict mathematical expertise to a limited group of *cognoscenti* with the need to divulge their achievements to a wider audience?

Practices of discipleship in the early modern age

At the turn of the 16th and 17th centuries, print publication became the most reliable way of disseminating scientific knowledge. The free and open exchange promoted by the advent of print books, academies, and erudite journals facilitated the communication of scientific ideas to a wider audience and allowed authors of scientific claims to circulate theories and findings via fixed and inalterable texts. Notwithstanding the advantages of this new system of communication, the process of transition between handwritten manuscripts and printed texts was not smooth. In the wake of the Pythagorean tradition, authors in the fields of mathematics and astronomy had long been disposed to revealing scientific knowledge only to a select audience through letters and manuscripts – a technique known as scribal publication – while they were reluctant to publish and share their findings with more general and amorphous readers. Scribal publication, indeed, allowed

mathematicians and natural philosophers to claim priority over a certain discovery without, at the same time, disclosing their core results to a broader and possibly hostile readership.[14]

The establishment of technically demanding academic disciplines of astronomy and newly mathematical natural philosophy at the dawn of the early modern age did not facilitate the transitional process between scribal and printing publication. Mathematics was at the very centre of the emerging new interpretation of nature; but it was difficult to understand and was – in an important sense – the property of a new group of experts, something to protect from 'little smatterers' (as Newton called them). During the 16th century, Copernicus advocated this message: with the publication of *De Revolutionibus Orbium Coelestium* (1543) not only did he promote a heliocentric view of the world, but he also affirmed the need for scholars to have mathematical expertise in that part of astronomy that dealt with the physical reality of the heavens. *Mathemata mathematicis scribuntur* became a rallying cry for later Copernicans, which recognized in this claim a sort of Pythagorean heritage. Indeed, in the preface of *De Revolutionibus*, the Polish astronomer had unequivocally depicted himself as a staunch Pythagorean, declaring his unwillingness to publish his work to avoid the comments of the "babblers" – or the unlearned.[15]

As numerous scholars have shown, Copernicus's demand for technical expertise was effectively a plea for astronomers to speak authoritatively in areas that had previously been the preserve of natural philosophers. However, in the rest of this thesis I argue that it also inaugurated a new template for the relationship between master and disciple, a structure that would constitute the foundations underpinning the successful transmission of varieties of the "new philosophy". It was only after engaging in an intellectually close relationship with the young mathematician Georg Joachim Rheticus, that Copernicus accepted his disciple's insistence on printing the work and trusted him with sorting out its publication and circulation. By accepting the growing importance of

[14] E. L. Eisenstein, *The Printing Revolution in Early Modern Europe* (Cambridge, 2015). A. Johns, "The Uses of Print in the History of Science", *Papers of the Bibliographical Society of America,* 107, no. 4 (Dec. 2013), 393–420.
[15] R. Westman*, The Copernican Question: Prognostication, Skepticism and Celestial* Order (University of California Press, 2011).

the print culture of his time, the Polish astronomer had eventually chosen to disseminate the core of his doctrine to a wider audience. His strategy, however, did not consist of an uncontrolled circulation of his findings; Rheticus represented the intermediary between the author and his readership.

In the decades following the publication of *De Revolutionibus*, novel discipleship practices became essential to the development and spread of the new mathematized natural philosophy. Authors like Kepler, Galileo, and Newton were pronouncing radically novel statements – according to what was known at their times – based on the authority of mathematics combined with observation and experiments. Making such knowledge credible even to a non-literate audience required the mediation of trusted and expert disciples able to disseminate sophisticated mathematically-grounded arguments. By cultivating disciples, authors dealing with the objective difficulties of their findings balanced their concern for limiting access to their work while recognising the growing importance of the public dimension of natural philosophy.

At this point, a clarification is needed: what does the word "disciple" mean and how was it used in the context of the early modern scientific culture? Etymologically, the Latin expression *discipulus* referred to the pedagogical process of learning from a master. It was only when the Biblical text borrowed this term from the Latin world, however, that it assumed specific nuances: after the Christian era, the expression "disciple" began to designate those most dedicated proselytes that followed Jesus's great commission, becoming so the primary apostles of his Gospel.[16] The Christian significance of this expression became prevalent in the following centuries. In the early modern scientific context, for example, religion was not involved in the pedagogical process between a master and his students – on the contrary, sometimes they had different creeds. Discipleship, however, was still used as a metaphor; after a period of training under the master, the disciples were called to an apostolic mission of evangelization: they spread the word. And of

[16] For a comprehensive reference of the meaning and interpretation of the word "disciple" in the Bible see: C. M. Furey, J. LeMon, B. Matz, T. Römer, J. Schröter, B. Dov Walfish, E. Ziolkowski (eds.), *Encyclopedia of the Bible and Its Reception* (De Gruyter: Berlin/Boston 2012), Vol. 6, pp. 887-920.

course, a disciple accepted the apostolic mission because he believed in the mathematically demonstrated new system of the world that the master was proposing.

Early modern scholars were attentive to the nuances that surrounded the use of the term "disciple", and in many places we can observe their uncertainty about the right word to use to describe the person who was a student of a particular master. Expressions like "pupil" or "follower" could express the general sense of the term in certain circumstances but they did not grasp its essence. What features transformed a mere pupil into a devoted disciple, and what were the central differences between a follower and a disciple? The term "pupil" usually referred to a person who was taught by a tutor or an instructor; the expression 'follower' could apply to people who attached themselves either to the person or beliefs of another without the implication of personal contact; only the word 'disciple' implied a devoted allegiance to the teachings of one chosen as a master.

In addition to the meaning of the term "disciple", we can discern the impact of the Christian culture on the early modern world also in relation to the practices connected to the creation of master-disciple bonds. When during the Early Middle Ages the Church became patron of knowledge, monasteries and convents began to spread rapidly throughout Europe, and with them libraries and scriptoria where scholars could work in silence and solitude after having been rigidly trained by elderly monks. Most of the studies focused on this period invariably highlight the importance of the master's role in the pedagogical process, suggesting a vertical and one-way transmission of knowledge that lasted even when the monastic institutions evolved into Cathedral schools and, some decades later, into universities. The relationship between master and disciple, indeed, represented a simplified and uninterrupted chain of transmission of knowledge and authority.[17]

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[17] On medieval learning see: M. Long, T. Snijders, S. Vanderputten, *Horizontal Learning in the High Middle Ages. Peer-to-Peer Knowledge Transfer in Religious Communities* (Amsterdam University Press: Amsterdam 2019); M. Münster-Swendsen, "The Model of Scholastic Mastery in Northern Europe c. 970-1200", in S. N. Vaughn, J. Rubenstein (eds.), *Teaching and Learning in Northern Europe 1000-1200* (Brepols Publishers: Turnhout, 2006), pp. 318-356; G. Ferzoco, C. Muessig, *Medieval Monastic Education* (Leicester University Press: London, 2000); M. Long, *Learning as Shared Practice in Monastic Communities, 1070-1180* (Brill: Leiden, Boston, 2022); S. Steckel, N. Gaul, M. Grünbart, *Networks of Learning. Perspectives on Scholars in Byzantine East and Latin West, c. 1000–1200* (LIT Verlag: Münster, 2014).

Anatomy of the master-disciple relationship

Before analysing the main features of the master-disciple relationship in the early modern period, it is important to mention the general approaches that historians have adopted over the last decades on the topic of discipleship. In this sense, *Les enfants de Socrate* by Francoise Waquet,[18] provides a general account on the evolution of this intellectual bond in France and Italy in the twentieth century but include also other Western nations and goes back to the 17th century. The problem that Waquet faces in her work is the apparently irreducible conflict between institutional realities and subjective experience. If the study of institutions and disciplines cannot shed light on it, Waquet proceeds instead by illuminating it from within and looks at how masters and disciples actually lived, understood, and imagined this personal dimension. Waquet seems to suggest that what is really transmitted is more closely bound up with the personal and non-institutional interactions of the players. The central chapters of her book, indeed, explore the affective and imaginary aspects of the master-disciple relationship, in other words the feelings that bind, and the metaphors that construct, this intellectual couple. The complex nature of the master-student relationship reflects the wide net of sources that Waquet considers in her study, which relies on an eclectic body of texts comprising intellectual autobiographies, prefaces, dedications, acknowledgments, correspondences, letters of recommendation, inaugural lessons, eulogies, homages, and obituaries.

My approach to this topic owes a lot to Waquet's work. A comprehensive analysis of the master-disciple relationship, indeed, cannot prescind from the investigation of the personal bond established by the individuals concerned. Unlike Waquet's book, however, in my work this aspect is examined in strict relation to the institutional setting and to the changing nature of disciplines that characterized the early modern period. In this sense, my analysis builds on Robert Westman's approach, in particular on his book *The Copernican Question: Prognostication, Skepticism and*

[18] F. Waquet, *Les enfants de Socrate: filiation intellectuelle et transmission du savoir, XVIIe-XXIe siècle* (Paris: Albin Michel, 2008).

Celestial Order[19] and on his paper *The Astronomer's Role in the Sixteenth Century: A Preliminary Study*.[20] It was the general acceptance of the heliocentric system and the consequent emergence of a mathematically-informed natural philosophy that promoted the development of a new kind of discipleship. Only by considering these aspects as connected we can appreciate all the nuances of the complex dynamics that animated the early modern scientific world.

During the early modern period, the master-disciple relationship had specific features that distinguished it from other intellectual and pedagogical connections. Firstly, it is important to say that every relationship of this kind began with a consenting, reciprocal choice: on the one hand, the disciple chose a master with a prominent intellectual power and reputation and espoused his cause; on the other hand, the master selected among his students – or among his intellectual acquaintances – the most talented and brilliant minds. How was the pupils' potential recognised, and what did it consist of? The first letters that the disciples wrote to introduce themselves to the master provide an answer to this question and allow to individuate a common pattern among the acolytes belonging to the same circle. The first contact between master and disciple, indeed, was not always direct – older disciples sometimes acted as intermediaries between the master and his new acolytes – and could take place either inside or outside the institutional context. During the 17th century, the academic milieu represented the main centre to pass on scientific knowledge, but not the only one. Many influential mathematicians and natural philosophers, for example, continued to teach privately even when they had reached important university positions. The flourishing of scientific academies throughout the European continent, moreover, inaugurated new practices and methods for developing and communicating knowledge, with the consequent creation of new opportunities for ambitious students to become acolytes of a well-known author.

The first meeting within the domain of mathematically-informed natural philosophy represented a turning point for the disciples: it was an exceptional moment of their existence and

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[19] R. Westman*, The Copernican Question: Prognostication, Skepticism and Celestial Order*.
[20] R. S. Westman, "The Astronomer's Role in the Sixteenth Century: A Preliminary Study", *History of science; an annual review of literature, research and teaching*, 18 (1980), pp. 105-147.

defined dramatically a before and an after in their intellectual life. Often the disciples defined their first encounter with the master as a revelation, a dazzlement, with a language that refers to a sort of mystical experience. When they accepted membership of a circle, indeed, some disciples experienced a sort of intellectual conversion: they reoriented their philosophical beliefs and began to adopt their master's worldview, language, or system of theories. Most of the time this process required a period of contact between master and disciple; because of their technical – and revolutionary – nature, the topics in question were difficult to digest even for trained mathematicians and required the master's guidance. The case of Copernicus and Rheticus effectively illustrates this occurrence: when in 1538 the latter arrived in Frauenburg, where the former resided at the time, he was subjected to intense training in order to master Copernicus's astronomical work and his observational method. On many occasions, master and disciple could not meet personally and devised alternative solutions to communicate: either older disciples acted as intermediaries, or long-distance training was entrusted to epistolary exchange.

However it occurred, the period of contact between master and disciple represented an important pedagogical moment: on the one hand, the disciple could access his master's most recondite theories and findings which, sometimes, were not even published yet; on the other hand, the master could benefit from the keen inquiries of smart and talented mathematicians who, in some cases, proved to be even more brilliant than the master himself. Besides this, the personal contact constituted an essential stage in building trust. Trust was an essential feature in the process of making scientific knowledge during the early modern age.[21] At the turn of the 16th and 17th centuries, astronomers were very careful in sharing their massive collections of data – which required years of observation and hard work – only with trusted collaborators or disciples. This caution was exacerbated when, after the counter-reformation, the ecclesiastic institutions exercised vigilant control over the publication of texts in astronomy and natural philosophy within Catholic

[21] S. Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century* (Chicago: Chicago University Press, 1994)

territories; if they fell into wrong hands, certain unorthodox theories could seriously endanger their authors. Moreover, during the 17th century – and beyond, natural philosophers and mathematicians were often involved in intellectual disputes and quarrels that required the help and support of loyal and trusted wingmen. The disciples, indeed, shared with their master his friends but also his enemies.

In the context of disputes and quarrels, being surrounded by a consistent number of disciples represented a significant advantage; each disciple was instrumental in fighting the master's cause. Sometimes early modern mathematicians and natural philosophers let their disciples publish harsh replies to their opposers, although often these texts were written by the masters themselves. At other times the disciples acted as ambassadors to ease a tense situation, and occasionally, they oversaw gathering information that served their master's cause. What motivated a disciple to expose – and sometimes compromise – his name at the behest of the master? This question does not have a specific answer; indeed, several reasons moved a young mathematician to dedicate his life and work to a certain master and his cause. Firstly, the master-disciple relationship was implicated in a broader patronage structure: in return for defending their cause, masters had a sort of obligation to help their disciples achieve important academic positions. This had reciprocal advantages: on the one hand, the disciple obtained a prestigious chair in a distinguished university; on the other hand, this practice allowed the master to build a strategic network of trusted people operating inside the institutional context.

Another reason that motivated a disciple to commit himself to a master consisted in the consideration of the master himself, who was often deified in a manner that recalls the Pythagorean tradition. The master was a revolutionary figure of knowledge who possessed a superior erudition. These traits of superiority that the disciples recognized in their master together with the age gap between the two parties constituted an important element in creating a hierarchical order within the circle. The master was also invariably appreciated for his moral and human qualities, a fact that made his conduct a central facet of the model to follow and imitate. This inclusion of moral

elements in the intellectual portrait refers to an ideal that took form in the 17th century: the perfect natural philosopher had to possess a number of qualities referring to the notion of 'humanities' in order to better serve the cause of knowledge, in particular to facilitate its communication.[22] A similar concept, however, can be also traced in the medieval university context, in which the master derived his power from being both a man of letters and an image of virtuous perfection. At the time, *litterae* and *mores* were strictly interconnected; high medieval educational structures, indeed, aimed at producing a man who possessed both.[23]

In the Late Middle Ages as well as during the early modern period, the focus on the master's *humanitas* played a relevant role in shaping the relationship with his disciples as personal and intimate: in the letters between the two parties, words of admiration, respect, and gratitude were often combined with expressions of endearment, affection and, in certain cases, *caritas*. Sometimes the closest disciples shared with the master board and lodging – a practice comparable to the monastery tradition; other times, by marring the master's daughters they became part of the family. Such proximity contributed to creating a special link with certain disciples rather than with others; especially when they were approaching the end of their careers, early modern mathematicians tended to rely on young acolytes who, after becoming their favourite pupils, usually inherited the intellectual legacy of their masters.

Evidently, the master-disciple relationship had a precise and specific purpose: the transmission of knowledge. The disciples, however, were active recipients of this knowledge, trained not only to understand but also to develop and improve their master's findings in a dynamic form that combined respect for tradition and a commitment to innovation within it. During the early modern age, the disciples' tasks grew in number and importance: the increasingly public dimension of science reoriented the communication of theories and findings and the disciples became precious

[22] P. Dibon, "Communication in the Respublica literaria", in P. Dibon, *Regards sur la Hollande du siècle d'or* (Naples: Vivarium, 1990), pp. 160-162.
[23] S. N. Vaughn, J. Rubenstein (eds.), *Teaching and Learning in Northern Europe 1000-1200* (Brepols Publishers: Turnhout, 2006); G. Ferzoco, C. Muessig, *Medieval Monastic Education* (Leicester University Press: London, 2000).

allies to disseminate highly technical knowledge even to a non-literate audience. On many occasions, they authored and published simplified versions of their masters' works; other times, they lectured their students – or some of them – on their master's mathematical and astronomical theories. In each case, it was possible to recognize in the disciple's action the affiliation to a certain master and to his school of thought.

This occurrence recalls the world of art: the analysis of the stylistic features of a painting suggests its author's membership in a certain workshop – thus, his attachment to a specific master. The comparison between art and science in relation to discipleship provides interesting points of reflection; the transmission of technical knowledge, indeed, allows us to individuate common features between these two disciplines. In many cases, the training that young students of science received from their masters did not differ from the apprenticeship that young painters received in their masters' bottega.[24] Besides, when at the beginning of the 11th century the first universities began to flourish in Bologna, Paris, and Oxford, they mirrored the model of guild and associations, where students were apprentices enrolled under a master.

The world of art: discipleship within the walls of a bottega and beyond

During the second half of the 15th century, the head of the monastic Church of San Salvi (near Florence) commissioned the Italian *maestro* Andrea del Verrocchio to paint the Baptism of Jesus by John the Baptist as recorded in the Gospels of Matthew, Mark, and Luke. The painting – today housed in the Uffizi Gallery in Florence – was completed around 1475 and soon caused excitement not only for its technical features but also for the circumstances that surrounded its execution. The *Baptism of Christ* – as the artwork has become known – is one of the most tangible and concrete pieces of evidence of the collaboration between a master and his students within a fifteenth-century Florentine workshop. The master, Verrocchio, did a large part of the painting

[24] N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method* (MIT Press, 2009), p. 345-6.

using tempera on wood while one of his pupils painted the angel on the left side and touched up some other areas – including part of the distant landscape – using the new technique of oil paint. The pupil in question was Leonardo da Vinci and a legend tells that his contribution was so far superior to his master's that the latter, after the completion of that artwork, put down his brush and never painted again. After the mid-1470s, indeed, Verrocchio dedicated himself principally to sculpture.[25]

Verrocchio's bottega was one of the most important and stimulating workshops for any young and curious artist of Medicean Florence. Several prestigious artists including Domenico Ghirlandaio, Pietro Perugino, Sandro Botticelli, and Lorenzo di Credi served their apprenticeships there. At the time, apprenticeship constituted a rather exclusive form of training; in his *Craftsman's Handbook* – written between 1390 and 1437 – the Italian painter Cennino Cennini recalled that enthusiastic novices "want to find a master; and they bind themselves to him with respect for authority, undergoing an apprenticeship in order to achieve perfection".[26] The trainees paid a substantial fee to attend a certain bottega; the master, on the other hand, provided his students with an education but also with board and lodging. Most of the time, moreover, he acted towards some of his apprentices *in loco parentis* – a fact that explains why the bottega usually admitted no more than three pupils at a time. The constant presence and the assiduous collaboration contributed to establishing trust and made the relationship between the master and some of his students closer. Certain pupils, indeed, became trusted disciples. During his frequent trips to Venice, for example, Verrocchio used to entrust his favourite pupil Lorenzo di Credi with the direction of his Florentine workshop. Di Credi, then, became the administrator and principal heir of Verrocchio's estate after his master's death.

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[25] A. Butterfield, *Verrocchio: Sculptor and Painter of Renaissance Florence* (Princeton University Press, 2021) F. Caglioti, A. De Marchi (eds.), *Verrocchio: master of Leonardo* (Venezia: Marsilio Editori, 2019). L. Kanter, *Leonardo: Discoveries from Verrocchio's Studio: Early Paintings and New Attributions* (New Haven, CT: Yale University Press, 2018). C. Neilson, *Practice and theory in the Italian Renaissance workshop: Verrocchio and the epistemology of making art* (Cambridge: Cambridge University Press, 2019). R. McKie, *Leonardo da Vinci: pupil, painter and master* (London: National Gallery Company, 2011).

[26] C. Cennini, *The Craftsman's Handbook*, edited and translated by D. V. Thompson (New Heaven, 1933).

The artist's apprenticeship, which lasted up to seven years, usually began with the practice of copying.[27] This activity evoked the classical concept of *imitatio*, which for Latin authors meant imitation of the style of great artists. In every Renaissance artistic workshop, there was a vast repertoire of drawings which the students copied and re-copied endless times until they mastered the technical ability that made them worthy to work alongside their master. With the drawing models, thus, the master taught his pupils about his technique and style; but he also transmitted to them his philosophy of art. The pupils, on the other hand, exercised their skills in imitation of their master. Concerning this aspect, in a sermon of 1493 the Italian Dominican friar Girolamo Savonarola claimed:

> What does the pupil look for in the master? I'll tell you. The master draws from his mind an image which his hands trace on paper and it carries the imprint of his idea. The pupil studies the drawing and tries to imitate it. Little by little, in this way, he appropriates the style of his master.[28]

The practice of copying promoted the creation of a common 'language' among the artists working within the same bottega, so much so that even today it can be very difficult to attribute the works that came out of a workshop to the hand of the master or to one of his students. For this reason, scholars have often stigmatized the exercise of copying as a mechanical artistic practice, implying the appropriation of others' ideas and the lack of originality on the apprentices' part. On the contrary, this practice provided the students with the technical foundations to deviate from the master's exempla and encouraged them to give space to their own creativity. In the Middle Ages, painters and sculptors were considered high-quality craftsmen valued mainly for their skills rather than their intellect.[29] Works of art were commissioned by wealthy patrons, who expected artists to follow orders rather than to express their own vision. Imaginative licence and expressive powers were neither expected nor valued. Things began to change in the early Renaissance. With the

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[27] In the workshop, the master exposed the apprentices to both theoretical training and a wide range of technical skills, which included drafting, metal working, plaster casting, leather working, mechanics, and woodwork, as well as the artistic skills of drawing, painting, sculpting, and modelling. F. Ames-Lewis, *Drawing in Early Renaissance Italy* (New Haven: Yale University Press, 1981). A. Thomas, *The Painter's Practice in Renaissance Tuscany* (Cambridge, 1995).
[28] C. Gilbert (ed.), *Italian art 1400 1500. Sources and Documents* (Englewood Cliffs, NJ: Prentice-Hall, 1980), p. 156.
[29] A. Martindale, *The Rise of the Artist in the Middle Ages and the Early Renaissance* (London, Thames and Hudson, 1972). K. E. Barzman, *The Florentine Academy and the Early Modern State. The Discipline of 'Disegno'* (Cambridge: Cambridge University Press, 2000).

rediscovery of classical art and the advancement of new techniques such as the use of oil paint and perspective, increasing value was placed on artistic innovation and creativity.[30] This aspect is testified by the production of numerous variations of the master's painting within the same workshop. The cases of Leonardo da Vinci's *Madonna del Gatto*, *Salvator Mundi*, and *Cristo Porta Croce*, for example, tell us that from 1495 onward, Leonardo's apprentices became gradually independent in the pictorial development of their master's graphic ideas. The variety of solutions on these subjects, indeed, attests that the *Leonardesque* artists did not just copy a single model but interpreted the master's drawings that were made available to them.[31]

The production of variations was an important exercise for apprentices; moreover, it is likely that Leonardo himself, under pressure from the high demand and increasingly impatient with the practice of painting,[32] delegated the execution of some commissions to his disciples. Nonetheless, the master continued to supervise his pupils and to correct and retouch their works, as it appears especially in drawings. Leonardo was completely generous in making his knowledge available to his pupils, but he was also convinced that "tristo è quell discepolo che non avanza il suo maestro" (he is a poor disciple who does not excel his master). Besides the technical aspects, indeed, the Italian painter aimed at transmitting to his students the intrinsic value of his art, with the hope that, by exceeding and preserving the master's teachings, his disciples would spread his artistic ideas and make a significant contribution to the success of his inventions.

During the early Renaissance, the workshop gradually evolved into a site of more sophisticated artistic practice, with artists increasingly engaged in intellectual activities like perspective, foreshortening and anatomical drawing. Manual skills were combined with the study of mathematics, geometry, anatomy, classical culture, theology, and philosophy. Artists began to

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[30] R. Weiss, *The Renaissance Discovery of Classical Antiquity* (Oxford, 1969).
[31] D. A. Brown, *Leonardo da Vinci: art and devotion in the Madonnas of his pupils* (Cinisello Balsamo, Milano: Silvana, 2003). W. Suida, *Leonardo e i leonardeschi* (Vicenza: Neri Pozza, 2001). F. Rinaldi, "Academia Leonardi Vinci. Gli allievi di Leonardo e la fortuna dei modelli del maestro", in P. C. Marani, M. T. Fiorio, *Leonardo da Vinci 1452-1519: the design of the world* (Milano: Skira, 2015), pp. 438-49.
[32] On 3rd April 1501, Fra Pietro da Novellara recalled that Leonardo was most impatient with the brush (impacientissimo al pennello) and interested almost exclusively in geometry.

believe that their profession deserved a higher status; they encouraged a wider recognition among their audience and contributed to the idea that painting, sculpture, and architecture should be considered one of the "liberal arts" rather than a menial trade.[33] The evolution of the bottega into a more intellectual place culminated during the second half of the fifteenth century when Lorenzo de' Medici established in Florence the celebrated "Giardino di S. Marco".[34] This place, intended as an art school where promising young artists could study under the supervision of the master Bertoldo Di Giovanni, did not offer a systematic programme of study; nonetheless, it provided opportunities for intellectual development without the constraints of the bottega organisation. The "Giardino di S. Marco" represented the deliberate precursor of the 'Accademia del Disegno', established in Florence in 1563 by Cosimo I de' Medici. This institution progressively incorporated intellectual characteristics into the early Renaissance apprentice's training and became the fulcrum of the artistic production in Tuscany.

Masters, disciples, and the secrets of music

The field of music, like the world of art, furnishes interesting clues to understanding nuances of the master-disciple relationship in the early modern age. During the early Renaissance, approaches to the acquisition and transmission of musical expertise were unformed and unfixed. Universities had only a modest part in the teaching of music; as part of the quadrivial disciplines, indeed, music was primarily an object of interest to natural philosophers intrigued by the harmonic-mathematical aspects of music theory and by its cosmological implications. In this context, there must have been a good deal of private instruction. The apprenticeship in the workshop of a maestro – either an instrument maker (especially luthiers) or a composer – constituted the only way to get proper education in music.[35]

[33] F. Ames-Lewis, *The Intellectual Life of the Early Renaissance Artist* (Yale University Press, 2000).
[34] P. Barocchi (ed.), *Il Giardino di San Marco. Maestri e compagni del giovane Michelangelo* (Firenze: Silvana, 1992).
[35] R. E. Murray, S. F. Weiss, C. J. Cyrus (eds.), *Music Education in the Middle Ages and the Renaissance* (Indiana University Press, 2010); P. O. Kristeller, "Music and Learning in the Early Italian Renaissance", *Journal of Renaissance and Baroque Music*, Jun., 1947, Vol. 1, No. 4, pp. 255-274.

Musical treatises – usually written by the masters – constitute an important source for understanding significant aspects about musical learning during the early modern period.[36] These pedagogical texts could assume different forms: sometimes they were composed as classic encyclopaedic textbooks from which the student learned by digesting the material that the teacher put in the appropriate pedagogical form;[37] at other times they assumed the form of dialogues in which a model student accepted the challenges that the master presented – the former's successes (or failures) provided object lessons for the reader.[38] On other occasions, the writer provided a glimpse into the reality of actual teaching, imparting clues to his own pedagogical agenda, to the materials that he provided for his audience, and even to the ways in which the students reacted to the instruction that they received.[39] While the first and the second approach assumed that musical knowledge would be gained by the reader through solitary study and passive learning respectively, only the third approach emphasised the advantages that the one-on-one teaching provided to the students as an active and pragmatic method.

The technical character of musical knowledge made the instruction by a master crucial for his students. Personal contact, indeed, had several advantages. As the Italian composer Ludovico Zacconi mentioned in his treatise *Prattica di musica* (1622), for example, he used to share with his pupils all the secrets of the *contrapunto*, a technique used to create simple polyphony (usually liturgical) either in improvised or written form. This was not a granted procedure: it was not guaranteed that a musician would reveal his most valuable secrets to his students.[40] According to Zacconi, for example, Costanzo Porta once commented to one of his students that "for a thousand

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[36] E. Nolte, "Didactic Considerations of Music Teaching in Some Compendiums for Musical Instruction from A.D. 1600", *Bulletin of the Council for Research in Music Education*, Spring, 1987, No. 91, Eleventh International Seminar on Research in Music Education (Spring, 1987), pp. 138-142.
[37] See G. Zarlino, *Le istitutioni harmoniche* (Venice: Francesco Senese, 1558).
[38] T. Morley, *A plaine and easie introduction to practicall musicke* (London: Peter Short, 1597).
[39] L. Zacconi, *Prattica di musica seconda parte. Divisa, e distinta in quattro libri* (Venice: Alessandro Vicenti, 1622).
[40] "So far, many excellent musicians on the verge of death prefer to take to the burial their rare knowledge rather than to leave it in writing to everyone who wanted to have it. And the living, who still live among us, holding the best [sc. knowledge] in their pocket for their own advantage do the same, although they use it only on some occasions, without having the community of pupils an occasion to participate." In L. Zacconi, *Prattica di musica,* p. 5.

ducats I would not have given out the secrets that this Brother [sc. Zacconi] has."[41] On the other hand, the masters carefully selected the most talented pupils to teach. According to the Dutch author Adrianus Petit Coclico, Josquin des Pretz – composer of High Renaissance music and central figure of the Franco-Flemish School – believed that the teaching of composition was reserved only for those 'who were drawn to this delightful art by a special natural impulse.'[42]

The reciprocal choice between master and disciple is one of the main topics that the Italian music theorist Domenico Pietro Cerone discussed in his monumental work *El melopeo y maestro*, consisting of 1160 folio pages and published in Spanish in 1613.[43] As the title suggests, this text was intended not only for the education of the makers of music (*el melopeo*), but also for the preparation of their teachers (*el maestro*). In his treatise, indeed, Cerone delved deeply into the character of both master and pupils, taking into consideration the features of their interaction. Relevant topics in this sense concerned the approach to teaching, the obligations and qualities of a good maestro, the criteria for choosing such a maestro, the appropriate disciplining of students, and the benefits of correction.

In his text, Cerone often emphasized the importance of the personal contact between master and student, not only in relation to pedagogical issues but also with regards to moral and social behaviours: "the Master must be the guide of the student; he must be the staff with which the student sustains himself in his first steps; and for this, it is necessary that the Master be without defect, since the child will learn to walk badly if the guide wavers".[44] On the other hand, the students were strongly encouraged to follow the master's example and to revere him without assuming the mere appearance of learning in search of renown. Only the establishment of a

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[41] *Ibid.*
[42] A. P. Coclico, *Compendium musices* (Nuremburg, 1552), sig. F2v. Cited and translated in John Milsom, "Analysing Josquin," in Richard Sherr (ed.), *The Josquin Companion* (Oxford: Oxford University Press, 2000), p. 431.
[43] D. P. Cerone, *El melopeo y maestro: tractado de música theorica y pratica; en que se pone por extenso; lo que uno para hazerse perfecto musico ha menester saber* (Naples: Gargano & Nucci, 1613).
[44] D. P. Cerone, *El melopeo y maestro*, chapters 72-73.

relationship based on respect and reciprocity could lead masters and students toward their common goal of musical perfection.

A particularly informative passage in *El melopeo y maestro* also concerns the student's relationship with non-musicians. According to Cerone, "it is not an appropriate thing to discuss Music with every type of person, nor all the time." He continues: "Let us also place in the catalogue of the disturbed those indiscreet persons who, with a disordered appetite, exert themselves much too much discussing and speaking of Music with persons who are not of the art, nor even (which is worse) afficionados of it."[45] Thus, Cerone strongly recommended to students of music that they converse only with people who appreciated the art, suggesting that they not impart the most important secrets to the "uninitiated". This feature indicates that he aimed to create a circle of literary men educated in music and able to engage in discussions on its technicalities – an aspect that resembles the same goal in similarly abstruse fields of art and science. Discipleship represented the privileged way to learn the art from prominent masters and to develop the ability to recognize, among others, the most talented and expert musicians with whom to communicate.

Chapter outline

This work is structured in six chapters that explore both chronologically and thematically the master-disciple relationship in different contexts and circumstances. In Chapter I, I analyse Copernicus's case and I highlight the main features of an exemplary master-disciple relationship which, in the following decades, inspired mathematicians and natural philosophers throughout the European continent. In the preface of *De Revolutionibus,* the Polish astronomer unequivocally depicted himself as a staunch Pythagorean who had not published his work on the heliocentric theory before being reluctantly convinced by friends to do so. According to Copernicus, mathematical teachings should not be indiscriminately diffused to the layman; instead, they should

[45] D. P. Cerone, *El melopeo y maestro*, chapters 147-48.

be reserved for a learned and circumscribed elite of expert mathematicians. Only after engaging in an intellectually close relationship with Rheticus did Copernicus accept his disciple's insistence on printing the work and trust him with managing its editing, printing and circulation. Through the publication and (posthumous) dissemination of a printed book, Copernicus established a Pythagorean model: recondite, technical natural philosophy required a discipleship structure.

In the context of the 16th-century reformation of the German educational system, Johannes Kepler enthusiastically embraced his dual roles in highly significant master-disciple relationships. As I show in Chapter II, when he was a student at Tübingen, Kepler offered himself up as a pupil and acolyte of the Copernican Michael Maestlin. Their interaction epitomized the traditional version of the master-disciple relationship within the academic context. However, when he became a master himself, Kepler operated in a quite different manner: he was not obliged to accept the strict institutional constraints imposed by a university and he established collaborative relations – based on Tycho Brahe's model – with talented assistants who helped him to carry on his calculations. Although we cannot use fixed schemes to define Kepler's relationship with his associates, we can nonetheless say that the German mathematician established important relationships which created a circle of learned mathematicians and astronomers who contributed to his academic projects. This was exactly as he had envisaged in a letter addressed to Galileo in 1597, in which he expressed his intention of building a community of experts in mathematics to establish the truth of the Copernican system.

Galileo neither replied to Kepler's letter nor adhered to his project. However, I show in Chapter III how he reinterpreted Copernicus's example by surrounding himself with a large and variable circle of acolytes who helped to spread his notions on mathematics, natural philosophy, and astronomy. In his attempt to establish a mathematically-grounded worldview, Galileo continuously struggled against conservative scholars and hostile institutions; he needed allies, but not generic ones. He trained talented students to master mathematics: only expert mathematicians could successfully argue against his enemies and carry on his pioneering scientific program; only

loyal disciples could share the value of the new mathematical natural philosophy underpinning his cosmology. Over the past decades, a number of significant studies of the so-called "Galilean school" have been published, collectively constituting a precious guide through the intricate network of people that surrounded Galileo. My research adds details to this picture in order to better understand the dynamics that animated the Italian intellectual milieu during Galileo's lifetime and beyond.

In chapter IV, I investigate the relationship between Isaac Newton and his tutor Isaac Barrow. Understanding how the teaching of mathematics evolved in England during the 17th century helps to frame Newton's mathematical education and allows us to understand how he became a master in turn. During the 1660s, Barrow participated actively in shaping a new professorship in Cambridge by inaugurating a new institutional figure – the Lucasian Professor of Mathematics. However, Barrow also created a new pedagogical role and, consequently, a different way for conceiving the master-disciple relationship in the field of mathematics. Newton was the most successful of the first generation of students to experience this new teaching system: in 1669, just one year after his MA graduation, he composed his first mathematical treatise, *De Analysi;* and in that same year he replaced Barrow as the Lucasian professor.

As I argue in Chapter V, Newton's jaundiced attitude to print culture conditioned the main traits of his role as a master. The English mathematician began his career under the impression that he could simply pass on his technically demanding work to a select band of friendly and competent readers via scribal publication. Once the necessity of publishing his doctrines in print became evident, however, the intrinsic difficulty of Newton's writings required the mediation of trained disciples able to manage the process of dissemination. The disciples became the primary medium between the master and his amorphous audience. In this chapter, I try to understand the reasons that moved the English mathematician to cultivate acolytes. Then, by analysing different cases, I investigate the actual practice of Newton's discipleship: firstly, I individuate the features required by the master to be part of his privileged circle; then, I analyse the disciples' initiation into

Newton's intellectual world; finally, I focus on the process of evangelization that the disciples operated in the field of natural philosophy, but also in the popularization of Newton's theology and philosophy.

An important aspect of Newton's discipleship concerns the role that the acolytes played in relation to his mathematical achievements. Newton's mathematical studies constitute one of the most complex aspects of his scientific enterprise. He worked effortlessly on mathematics not only to achieve ambitious results but also to corroborate, establish, and defend them. The development of Newton's mathematical achievements – and the dispute with Leibniz concerning priority in the invention of calculus – has been extensively studied by historians of mathematics. Little attention, however, has been devoted to Newton's cultivation of the network of disciples that contributed to the development of his mathematical results and to the establishment of his credibility, reputation, and authorship in that field. In Chapter VI, I analyse the fundamental role that discipleship played in the context of the priority dispute with Leibniz. During the last decade of the 17th century, the two mathematicians began to circulate their respective findings with different strategies: Leibniz adopted a policy that favoured the large-scale dissemination of his work while Newton preferred a controlled circulation of manuscripts and papers within a more circumscribed readership. Although different in nature and purpose, their strategies involved the participation of trusted acolytes. With the outbreak of the dispute, the role of discipleship became crucial: the series of events that followed, indeed, can be read only in relation to the multidimensional social milieus constituted by networks of disciples.

CHAPTER 1

COPERNICUS AND RHETICUS.

THE MEETING THAT CHANGED THE WORLD

A staunch Pythagorean

"Let no one ignorant of Geometry enter here" (Ἀγεωμέτρητος μηδεὶς εἰσίτω): according to tradition, this sentence was engraved at the door of Plato's Academy, the school that the Greek philosopher had founded in 387 BC in Athens. The authenticity of this admonition has been often questioned by historians; still, it is undeniable that in its spirit this motto encapsulates Plato's belief that mathematics – especially geometry – offered the finest training for philosophical minds. Many centuries later, in 1543, this famous adage was printed on the title page of Copernicus's *De revolutionibus orbium coelestium*.[46] Copernicus's intention, however, was less to establish a reference to Plato than to Pythagoras, as he made explicit in the prefatory letter to the Pope:

> Therefore I debated with myself for a long time whether to publish the volume which I wrote to prove the earth's motion or rather to *follow the example of the Pythagoreans* and certain others, *who used to transmit philosophy's secrets only to kinsmen and friends*, not in writing but by word of mouth, *as is shown by Lysis' letter to Hippasus*. And they did so, it seems to me, not, as some suppose, because they were in some way jealous about their teachings, which would be spread around; on the contrary, *they wanted the very beautiful thoughts attained by great men of deep devotion not to be ridiculed by those who are reluctant to exert themselves vigorously in any literary pursuit unless it is lucrative*; or if they are stimulated to the nonacquisitive study of philosophy by the exhortation and example of others, yet because of their dullness of mind they play the same part among philosophers as drones among bees.[47]

The message sent by the Polish philosopher is clear: by addressing himself to Pope Paul III, Copernicus justified his well-known reluctance towards publication and declared that noble and sublime teachings – like the ones contained in his book – should not be indiscriminately diffused to common people. Instead, in the wake of the Pythagorean tradition, they should be discreetly reserved for a learned and circumscribed elite.

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[46] See A. Koyré, *The Astronomical Revolution* (London: Methuen, 1973), p. 73 and I.B. Cohen, *Revolution in Science* (Cambridge, Mass.: The Belknap Press, 1985), p. 115.

[47] N. Copernicus, *On the Revolutions*, translation and commentary by Edward Rosen (Johns Hopkins University Press: Baltimore 1992), Preface.

To strengthen his message, in the preface to *De revolutionibus* Copernicus also mentioned the apocryphal letter written by Lysis to Hippasus in which the former blamed the latter for having publicly taught Pythagoras' mathematical teachings without consent.[48] The Polish astronomer had translated that letter into Latin and had planned to publish it in *De revolutionibus*. The letter, however, was not printed in the *editio princeps* of 1543; its first publication took place only in 1873, when it was published as part of the fifth edition of *De revolutionibus* edited by the Copernican Society of Torùn – Copernicus' native town.[49] Why did Copernicus mention this spurious concoction in the dedication of his masterpiece to the Pope? What "secrets of philosophy" was he protecting from the "babblers" (ματαιολογοι) – as he called the unlearned in the Preface of *De revolutionibus*?[50]

We could answer the first question by referring to the fictitious letter itself: Copernicus, like Lysis, aimed at preserving the "clean fresh water" (pure mathematics) from its commixture with the "dirt" (the vulgar eyes) and by publishing that document he made clear his intention to address only a circumscribed learned audience. Answering the second question, on the other hand, requires a more extended reading of the Preface, at least until when the author finally disclosed the spirit of its previous attestations: "*mathemata mathematicis scribuntur*",[51] he proclaimed; those ignorant of

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[48] Copernicus had found the letter inside a collection of a Greek epistolography (*Epistolae diversorum philosophorum, oratotum, rhetorum sex et viginti*) published in Venice in 1499. He later reworked its translation from the Greek together with the letters of Theophytlactus Simocattes, a 7th-century historian and poet. Copernicus's edition of Theophytlactus's letters in 1509 was his only publication before the *De revolutionibus*. See Copernicus, *The Minor Works*, ed. by Pawel Czartoryski (London: Macmillan, 1985), pp. 24-25; P. Casini, "The Pythagorean myth: Copernicus to Newton", in *Copernico e la questione copernicana in Italia*, ed. L. Pepe (Florence, 1996), 183–99. C. H. Kahn, *Pythagoras and the Pythagoreans: A Brief History*, (Hackett Publishing Company, 2001); A. Koestler, *The Sleepwalkers: A History of Man's Changing Vision of the Universe*, (New York, 1959), pp. 148-58.

[49] Instead Kuhn, *The Copernican Revolution*, p. 138, dilutes the significance of the letter, claiming that it "describes the Pythagorean and Neoplatonic injunction against revealing nature's secrets to those who are not initiates", but he is more interested in emphasising Copernicus's Neoplatonism ("it here exemplifies Copernicus' participation in the Renaissance revival of Neoplatonism discussed in the last chapter") and overlooks the fact that the reference is exclusively to Pythagoras, while Plato is not mentioned.

[50] Copernicus might well have borrowed the Greek word ματαιολογοι – and its meaning –from the third of the Pastoral Epistles in the New Testament. The letter, historically attributed to Paul the Apostle and addressed to Titus, instructs the latter about the character of the assistants he should choose in view of the pastoral difficulties peculiar to Crete. M. A. Robinson, W. G. Pierpont (eds.), *The New Testament in the Original Greek: Byzantine Textform* (Southborough, MA: Chilton Book Publishing, 2005), p. 524.

[51] In relation to this sentence, Westman tried to delineate the audience of learned mathematicians that Copernicus intended to address with his work (Leo X and Paul III, Cardinal Schönberg, Bishop Giese, and Paul of Middleburg). On the other hand, he also attempted to figure out the names of the untrained theologians that he presumably intended to exclude. In this sense, he quotes only the name of Lactantius, "otherwise an illustrious writer but hardly a mathematician". See R. S. Westman, "Proof, Poetics, and Patronage: Copernicus' Preface to De revolutionibus," in *Reappraisals of the Scientific Revolution*, ed. David C. Lindberg and Robert S. Westman (Cambridge: Cambridge

mathematics were not admitted to that kind of knowledge. By considering all the achievements reached in mathematics – and through mathematics – as enterprises of the greatest value and because of the technical difficulty that only a few learned mathematicians could cope with, Copernicus embraced intimately and entirely the Pythagorean message and proclaimed himself as a loyal and devoted upholder of the cult.

Copernicus's words from the preface to *De revolutionibus* support adequately his adherence to the Pythagorean model; his rallying cry "*mathemata mathematicis scribuntur*", however, represented much more than a simple reference to the centrality of mathematics and his affiliation to a tradition. Most of the events related to Copernicus's life and work, culminating in the publication of his masterpiece, were bound up with the perspective of a staunch Pythagorean who shared his mathematical theories only within a circumscribed circle of acolytes. This perspective explains why Copernicus, who had always refused the publication of his heliocentric views, nonetheless explored other channels of circulation while carefully selecting his audience. The curious story of his *Commentariolus* clarifies this point.

Probably written between 1510 and 1514, the *Commentariolus* presented a preliminary sketch of the heliocentric theory more amply discussed in *De revolutionibus.* The importance of the content of this pamphlet – and its consequent extension in Copernicus's major work – has been widely studied;[52] here I highlight its reception and circulation throughout the learned community of the first half of the 16th century. At the time, Copernicus was very careful in preserving his scientific achievements from the unlearned in order to share it only with a specific audience.[53] This scope necessitated a subtle strategy: controlling the circulation of ideas through the shaping of a limited readership – made by trusted followers – around a scribal publication.

University Press, 1990), pp. 167–205. See also Barker and Goldstein, "Patronage and the production of De Revolutionibus", in *JHA* 2003, 345-368.

[52] See the Introduction to *Three Copernican treatises: the Commentariolus of Copernicus, the Letter against Werner, the Narratio prima of Rheticus*, translated with introduction and notes by Edward Rosen, (New York: Octagon Books, 1971), pp. 1-53.

[53] He explained the reason of such attitude in the Preface of *De revolutionibus*: he trusted only "acute and learned mathematicians, […] as this discipline especially requires, […] willing to examine and consider, not superficially but thoroughly, what I adduce in this volume in proof of these matters".

Did the manuscript really circulate only through the limited canals that its author had established and designed for it? According to the surviving documentation, we cannot be certain. Nevertheless, the lack of any mention of the text either publicly or privately in any 16th-century intellectual milieu suggests that the *Commentariolus* did not circulate widely at the time.[54] Before 1530 there is only one possible reference to the book: Matthew of Miechow, a Krakow physician and medical professor, in inventorying his private library in 1514 mentioned "A manuscript of six leaves containing a Theorica [astronomy essay] in which the author asserts that the Earth moves while the Sun stands still". Either the information is unsound or, as requested by the Pythagorean-Copernican demand for silence, Matthew of Miechow did not reveal the existence of the precious copy to his circle of acquaintances; had he done so, the fact would be known.[55] Indeed, the first public mention of Copernicus's draft appeared only after 1530; apparently the *Commentariolus* had finally found its way throughout the erudite community.

A copied manuscript was presumably present in Rome in 1533, where the Austrian chancellor, Johann Albrecht von Widmanstadt, gave an account of the new astronomy and explained its principles to Pope Clement VII and his entourage. During the same period Tiedeman Giese, Bishop of Kulm, probably began to encourage and persuade Copernicus about the necessity for publishing the book in the expanded and more accurate version that the Polish astronomer had already written[56] – as the author explained to Pope Paul III in the Preface to *De revolutionibus*, using a standard Horatian rhetorical device:

> But while I hesitated for a long time and even resisted, my friends drew me back. Foremost among them was the cardinal of Capua, Nicholas Schönberg, renowned in every field of learning. Next to him was a man who loves me dearly, Tiedemann Giese, bishop of Chelmno, a close student of sacred letters as well as of all good literature. For he repeatedly encouraged me and, sometimes adding reproaches, urgently requested me to publish this volume and finally permit it to appear after being

[54] On the reception of the *Commentariolus* see A. Romer, "The Welcoming of Copernicus's De Revolutionibus: The Commentariolus and its Reception", in *Physics in perspective*, 1 (2/1999), pp. 157- 183.
[55] On Matthew's inventory, see A. Koyré, *The Astronomical Revolution: Copernicus - Kepler – Borelli,* translated by R. E. W. Maddison, (N.Y.: Cornell University Press, 1973), pp. 27-28
[56] Concerning the writing of *De Revolutionibus,* Koyré states: "We do not know exactly when Copernicus finished *De Revolutionibus Orbium Coelestium*. It was definitely not before 1530, seeing that he uses observations made in 1529; nor was it later, at least not much later, than 1531, seeing that he does not use observations of 1532". A. Koyré, *The Astronomical Revolution: Copernicus - Kepler – Borelli,* p. 25.

> buried among my papers and lying concealed not merely until the ninth year but by now the fourth period of nine years.[57]

On 1st November 1536, Nikolaus Schonberg, Cardinal Archbishop of Capua, wrote directly to the Polish astronomer and invited him to publish his discoveries.[58] In that letter, Schonberg also requested a copy to send to Dietrich von Reder, a member of the Curia; but as far as we know, Copernicus never satisfied this request. Despite the pressure exercised by his friends, Copernicus resisted and did not change his mind until the beginning of the 1540s. What and who eventually did convince him to publish the book? The story of the relationship begun in 1538 with a young professor of mathematics from the University of Wittenberg – Georg Joachim Rheticus – provides an answer to this question.[59]

Rheticus: the fruit of Copernicus's 'delightful gardens'

Rheticus, was born on 16th February 1514 in Feldkirch, an ancient Roman province of Rhaetia.[60] In 1532 he was admitted to the University of Wittenberg where, after obtaining the degree of Master of Liberal Arts, he was offered a position as professor of the "lower mathematics". At Wittenberg, Rheticus absorbed the spirit of Melanchthon's pedagogical reformation, as testified by the speech that the young professor delivered on occasion of his inaugural lecture. After enumerating the benefits of studying mathematics, Rheticus defined that discipline as "the most excellent part of Philosophy", pointing to the possibility – and the necessity – of investigating the motions of heavenly bodies through mathematics, for "there is no other entrance to celestial doctrine than Arithmetic and Geometry".[61]

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[57] "N. Copernicus, *De Revolutionibus Orbium Coelestium*, Preface. See R. S. Westman, "Proof, Poetics, and Patronage: Copernicus' Preface to De revolutionibus," p. 181-182.
[58] The letter written by Nikolaus Schönberg on 1st November 1536 was included in every edition of *De Revolutionibus.* It precedes Copernicus's dedication to Pope Paul III.
[59] For the relationship between Copernicus and Rheticus see R. S. Westman, *The Copernican Question. Prognostication, Skepticism, and Celestial Order* (University of California Press, 2011).
[60] D. Danielson, *The First Copernican: Georg Joachim Rheticus and the Rise of the Copernican Revolution* (New York: Walker & Company, 2006).
[61] *In arithmeticen praefatio Georgii Ioachimi Rhetici in Corpus reformatorum* (Halle, 1843), vol. XI, pp. 284–92. See also S. Deschauer, *Die Arithmetik-Vorlesung des Georg Joachim Rheticus, Wittenberg 1536* (Munich, 2003).

In 1538, enthralled by the prospect of learning 'something more' from the leading mathematicians of his time and supported by Melanchthon – who later stated that Rheticus was "born to study mathematics" – the young mathematician took leave from Wittenberg to visit the most important astronomical centres of the time. At first, he moved to Nuremberg where, attracted by the fame of the German polymath Johannes Schöner, he improved his astronomical and astrological competence.[62] After a few months, he travelled to Tübingen and Ingolstadt where he interacted with some of Johannes Stöffler's pupils[63] and with the renowned astronomer Peter Apian. Finally, "the fame of Master Nicolaus Copernicus in the northern lands"[64] convinced Rheticus to overcome the "consistent financial expenses" that the long journey to Frauenburg (now Frombork, Poland) required, and in late 1538 the young astronomer encountered Copernicus.[65] The two mathematicians had different ages, outlooks, origins, and religions; nevertheless, in a short period, they built a singular and strong bond that changed the course of their lives.

How did Rheticus learn about Copernicus and what convinced him to visit Frauenburg? From the letter that Melanchthon wrote on 15th October 1538 to Joachim Camerarius to recommend his protégé, we know that before leaving Wittenberg Rheticus had planned to visit Schöner in Nuremberg and Apian in Ingolstadt, while Copernicus was not mentioned at all. The visit to Frauenburg was probably planned in a second instance, when Rheticus was already on tour. It is likely that Schöner was his source of information: the young mathematician, indeed, could have read a copy of Copernicus's *Commentariolus* in Schöner's library. Moreover, when he left

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[62] Shöner's impact on Rheticus's education cannot be overlooked. In the dedicatory letter that Joannes Petreius published together with the astrological treatise *De iudiciis nativitatum* (1540) by Antonius de Monteulmo, the German printer wrote to Rheticus: "[…] our Schoener, by virtue of his extraordinary kindness, was not only delighted by your talent, but also generously imparted what he believed would be beneficial to you in this system of learning [sc. of the celestial motions]". See K. H. Burmeister, *Achilles Pirmin Gasser, 1505–1577: Arzt und Naturforscher, Historiker und Humanist* (Wiesbaden, 1970–75), vol. III, p. 20. The English translation can be found in N.M. Swerdlow, "Annals of Scientific Publishing: Johannes Petreius's Letter to Rheticus", *Isis*, 83 (1992), 273–4. See also J. Freely, *Celestial revolutionary Copernicus, the man and his universe* (New York: I. B. Tauris, 2014), p. 121.

[63] Professor of mathematics and astronomy at the University of Tübingen, Johannes Stöffler (1452-1531) had been succeeded by Philipp Imser.

[64] K. H. Burmeister, *Georg Joachim Rhetikus, 1514-1574: Eine Bio-Bibliographie*, (Wiesbaden: Guido Pressler, 1967), vol. III, p. 50.

[65] For an overview of this period of Rheticus's life and its background see R. S. Westman, "The Melanchthon Circle, Rheticus, and the Wittenberg Interpretation of the Copernican Theory", *Isis*, Vol. 66, No. 2 (Jun., 1975), pp. 164-193.

Nuremberg, Rheticus was presented with three bound volumes that contained several books: a 1533 edition of Euclid's *Elements*, Schöner's edition of Regiomontanus' *De triangulis Omnimodis*, three works published by Johnannes Petreius in 1534–5; Petrus Apian's *Instrumentum primi mobilis*, Geber's *De astronomia*, Witelo's *Perspectiva*, and the 1538 Greek edition of Ptolemy's *Almagest*. When in Frauenburg, Rheticus delivered those books to Copernicus together with a manuscript copy of the data collected by Bernard Walther (a pupil of Regiomontanus) relating to observations of Mercury. The data contained in Walther's account were later used by Copernicus to correct some parameters of his heliocentric theory; the Polish astronomer, however, incorrectly attributed some of them to Schöner. At the time it was not unusual for astronomers to agree to a reciprocal exchange of observational data. It is plausible that, when in Nuremberg, Schöner convinced Rheticus to undertake that journey with the additional purpose of offering some of his observational data to Copernicus, with the hope that the Polish astronomer would reciprocate that exchange.[66]

The personal contact between Copernicus and Rheticus excluded the necessity of an epistolary exchange – a fact that makes the precise nature of their interaction difficult to reconstruct. Some passages of Rheticus's works, nonetheless provide interesting information about their encounters. In the Preface to his *Ephemerides of 1550*, for example, the young mathematician recalled his training at Frauenburg and admitted that at the time, driven by "juvenile curiosity", he "wished to hasten to the stars' sanctuary". Copernicus sometimes blamed his pupil's "painstaking attention to details" and was bewildered by his "soul's honest thirst" so much so that "with a soft arm, he [sc. Copernicus] used to exhort me to take my hand off the Tables".[67] Once at Frauenburg,

[66] See P. Barker, B. R. Goldstein, "Patronage and the Production of De Revolutionibus", *Journal for the History of Astronomy*, XXXIV, 2003, pp. 345-368.
[67] Georg Joachim Rheticus, *Ephemerides Novae Sev Expositio Positvs Divrni Sidervm Et "synschematismōn" præcipuorum ad Ann. redemtoris nostri Iesv Christi Filij Dei*, Günter, 1550. English translation available in Jesse Kraai, *Die heliozentrische Providentia des Rheticus / Rheticus' Heliocentric Providence: a study concerning the astrology, astronomy of the sixteenth century* (Doctoral dissertation, Ruprecht-Karls-Universität Heidelberg, 2001), p. 288.

indeed, Rheticus worked intensely to digest Copernicus's theory; as he himself admitted, he employed "scarcely ten weeks to mastering the astronomical work of the learned man".[68]

Besides the heliocentric theory, during his stay at Frauenburg Rheticus became acquainted with Copernicus's observational method, which consisted in measuring the magnitude of the eclipses by employing images obtained from a camera obscura.[69] During the period of their interaction, the young mathematician assisted Copernicus in the observation of two partial solar eclipses in Varmia – one on 7th April 1540 and the other on 21st August 1541. Copernicus's method of observation became very popular among astronomers in the second half of the 16th century thanks to the account that Erasmus Reinhold published in the second edition of his commentary to the *Theoricae novae planetarum* (Wittenberg, 1542) – an account that derived from the description that Rheticus had provided to Reinhold between the end of 1540 or the beginning of 1541.[70]

In his *De libris revolutionum Copernici narratio prima* – better known as *Narratio Prima* (1540), Rheticus also provided an interesting account of how Copernicus processed his observational data:

> My teacher always has before his eyes the observations of all ages together with his own, assembled in order as in catalogues; then when some conclusions must be drawn or contributions made to the science and its principles, he proceeds from the earliest observations to his own, seeking the mutual relationship which harmonizes them all; the results thus obtained by correct inference under the guidance of Urania he then compares with the hypotheses of Ptolemy and the ancients; and having made a most careful examination of these hypotheses, he finds that astronomical proof requires their rejection; he assumes new hypotheses, not indeed without divine inspiration and the favor of the gods; by applying mathematics, he geometrically establishes the conclusions which can be drawn from them by correct inference; he then harmonizes the ancient observations and his own with the hypotheses which he has adopted; and after performing all these operations he finally writes down the laws of astronomy.[71]

This account, like many other passages of Rheticus's work, underlines Copernicus' reverence for ancient astronomers – especially Ptolemy. In his text, Rheticus often compared his master with the

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[68] E. Rosen, *Three Copernican Treatises: The Commentariolus of Copernicus. The Letter against Werner. The Narratio prima of Rheticus* (New York, 1939), p. 109.
[69] J. Włodarczyk, "Solar Eclipse Observations in the Time of Copernicus: Tradition or Novelty?", *Journal for the History of Astronomy*, 38 (2007), 351–64.
[70] E. Reinhold, *Erasmi Reinholdi Salueldensis Theoricae Novae Planetarum Georgii Purbachii... recens editae et auctae novis scholiis...* (Wittenberg, 1542), f. Z8.
[71] E. Rosen, *Three Copernican Treatises*, p. 163.

Alexandrian astronomer, "because my teacher shares with Ptolemy the good fortune of completing, with the aid of divine kindness, the reconstruction of astronomy".[72] By referring to Copernicus as a new Ptolemy, Rheticus set a rhetorical fashion that contemporary and later scholars followed: in 1545, the Dutch physician, cartographer, mathematician, and instrument maker Gemma Frisius referred to Copernicus as "another Ptolemy" in his *De radio astronomico et geometrico*,[73] and six years later, the German astronomer and mathematician Erasmus Reinhold mentioned the Polish astronomer as "another Atlas or Ptolemy" in the *Prutenicae tabulae coelestium motuum*.[74] In 1574, Tycho Brahe in his lecture on mathematics alluded to Copernicus's status as "another Ptolemy";[75] and Michael Maestlin on his copy of *De revolutionibus* wrote about Copernicus: "after Ptolemy, the prince of all Astronomers".[76]

The outcome of the interactions between Rheticus and Copernicus speaks loudly about the bond that the two mathematicians established during the period of their interaction. Rheticus arrived in Frauenburg in the second half of May 1539 and by the end of the summer not only had he mastered Copernicus's theory, but he had also composed an accurate account in which he outlined the arguments in favour of the new astronomy. Written in the form of an open letter to Johann Schöner, Rheticus's *Narratio Prima* was published in Danzig by the printer Franz Rhode in mid-February 1540. What convinced Copernicus to print his astronomical theory? And why did he entrust it to the young mathematician's words? Rheticus provided an answer to the first question in the *Narratio Prima* when, in the long encomium directed to the Duke of Prussia, he recalled the discussion between Tiedemann Giese and Copernicus concerning the publication of the latter's heliocentric theory. According to Rheticus, Giese's powerful arguments persuaded Copernicus to compose and disseminate his astronomical work. The Polish astronomer, however, at first decided

[72] E. Rosen, *Three Copernican Treatises*, p. 109. J. Włodarczyk (ed), *Narratio prima or First Account of the Books On the Revolutions by Nicolaus Copernicus* (University of Warsaw Press, 2015) p. 52.
[73] R. Gemma Frisius, *De radio astronomico et geometrico* (Antwerp, 1545), f. 28v-29r. See K. Galle, "Building on Ruins: Copernicus' Defense of Ancient Astronomers against Modern Critics", *Endeavour*, 32 (2008), pp. 94–100.
[74] E. Reinhold, *Prutenicae tabulae coelestium motuum* (Tübingen, 1551), sig. a. 4r.
[75] T. Brahe, *Opera omnia*, vol. I (Libraria Gyldendaliana, 1913), p. 149.
[76] O. Gingerich, *An Annotated Census of Copernicus' De Revolutionibus* (Leiden, 2002), p. 225.

to publish only planetary tables "with accurate rules but no proofs" so that "common mathematicians would have a correct calculus of the motions" while "true scholars would easily arrive, from the numbers set forth, at the principles and sources from which everything was deduced". This plan, Rheticus explained with words that anticipated Copernicus' later statement from the dedicatory letter of *De revolutionibus*, "would provoke no dispute among philosophers ... and the Pythagorean principle would be observed that philosophy must be pursued in such a way that its inner secrets are reserved for learned men, trained in mathematics, etc."[77]

Not satisfied by Copernicus' proposal. which, as it was for the *Alfonsine tables,* would produce "great inconvenience and many errors", Giese urged again the Polish astronomer to publish not only his planetary tables but also their underpinning astronomical theory, however revolutionary it was. This time, the bishop, a lifelong friend and a wealthy man, who had an excellent set of instruments that he made available to Copernicus, succeeded in his aim. Copernicus, indeed, agreed to disseminate his work; the publication of the *Narratio Prima*, intended as a preliminary account to test the reaction to Copernicus's new astronomy, was presumably part of that strategy. Aware of the unorthodoxy of his system, Copernicus did not underestimate the possibility of negative responses that could endanger himself (as a canon of the Catholic church) or his theory. Rheticus's *iuvenili audacia* was exactly what the Polish astronomer needed for his great discoveries to leave the shadows, and by giving him the honour of publishing a preliminary exposition of heliocentrism he found a way to come out publicly without nevertheless exposing his authority.[78]

The *Narratio prima* came off the press in March 1540 and in April, Rheticus sent several copies to scholars and friends. The book was welcomed favourably throughout Europe: congratulations and compliments arrived from the German printer Johannes Petreius, who appreciated Rheticus's "splendid description" and expressed his desire to see, one day, Copernicus' "glorious treasure"; Gemma Frisius, who hoped that Copernicus could "achieve a restoration [sc. of

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[77] E. Rosen, *Three Copernican Treatises,* p. 193.
[78] P. Barker, B. R. Goldstein, "Patronage and the Production of *De Revolutionibus*", *Journal for the History of Astronomy*, XXXIV, 2003, pp. 345-368.

this science] to a state of soundness and good repair"; and Andreas Osiander, who on 20th April 1541 congratulated Rheticus on his brilliant achievement, exhorting him to intercede with Copernicus in order to obtain his friendship.[79] Such favourable comments encouraged a second edition of the *Narratio Prima*, which was published again at Basel in July 1541 under the supervision of the physician Achilles Gasser. In a letter to Vögelin, Gasser described Rheticus' account as a book that "certainly departs from the manner of teaching practised so far", so much so that it "may even sound (as the monks would say) heretical. Nevertheless," he continued, "what it seems to offer is the restoration – or rather, the rebirth, of a true system of astronomy".[80] The letter continued with an exhortation: Gasser invited Vögelin not only to examine the book critically but also to send it "to all who cherish mathematics . . . Recommend that they read it too. Not only will this hasten the appearance of a further, fuller account. But a greater stream of requests will reach its author . . . imploring him to allow the delivery of his whole work to us." The publication of the *Narratio Prima* had raised the hope and the expectations of astronomers and mathematicians who desired to read the full account of a new astronomy. Now that the die was cast, Copernicus had little choice but to arrange the publication of his masterpiece.

Rheticus and Copernicus worked jointly to revise the text of *De revolutionibus* until at least June 1541, when the former reported that the latter was "in good health and very busy in writing".[81] At the time, the main draft of Copernicus' work was presumably close to completion; a few months later, indeed, Rheticus was called back to his duty at Wittenberg and left Frauenberg with the manuscript of *De revolutionibus* – or at least with most of it. The young mathematician took care of the editorial operations that followed: in May 1542, he delivered Copernicus' work to Petreius at Nuremberg and by the end of the month, he began to proofread the first leaves that came off the press. In early October, academic duties forced Rheticus to move again – this time to Leipzig where

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[79] For an account of the reception of Rheticus's *Narratio Prima* see A. Koyré, *The Astronomical Revolution: Copernicus - Kepler – Borelli*, p. 34; J. Freely, *Celestial revolutionary*, pp. 131-145.
[80] D. Danielson, *The First Copernican: Georg Joachim Rheticus and the Rise of the Copernican Revolution* (New York, 2006), p. 212.
[81] K. H. Burmeister, *G. J. Rhetikus* (Wiesbaden, 1967-1968), Bd. Ill, s. 27.

he took up a professorship in mathematics. The Lutheran theologian Andreas Osiander was then assigned to supervise the editorial operation and to proofread the final version of the book. The longed-for treatise was finally published in mid-April 1543 with the title *De revolutionibus orbium coelestium libri VI*.

One of the first copies of the book reached Rheticus at Leipzig shortly after the end of the printing operations. The young mathematician was certainly pleased to see the work of his master finally printed; at the same time, he was shocked, not only at the omission of the poem that he had commissioned from Joachim Camerarius to introduce Copernicus's book but also for the unexpected inclusion of an anonymous section entitled *Ad Lectorem* in which the heliocentric theory was presented as a mathematical model lacking any reference to the real description of nature. Both Petreius and Osiander denied their involvement in that unfortunate episode but only a few decades later, Michael Maestlin found a note among Philip Apian's books explaining the mystery of the added text:

> Concerning this letter [sc. Ad lectorem], I [sc. Michael Maestlin] found the following among Philip Apian's books (which I bought from his widow) . . . Georg Joachim Rheticus, the Leipzig professor and disciple of Copernicus, became embroiled in a very bitter dispute with the printer. The latter asserted that it had been submitted to him with the rest of the treatise. Rheticus, however, suspected that Osiander had prefaced it to the work, and declared that, if he knew this for certain, he would sort the fellow out in such a way that he would mind his own business and never again dare to slander astronomers. Nevertheless, [sc. Peter] Apian told me that Osiander had openly admitted to him that he had added this [sc. letter] as his own idea.[82]

Rheticus corrected Osiander's outrageous distortion by drawing with a red crayon a big X across the page containing the section *Ad Lectorem* of all the copies that he sent out to his friends.[83] Two of those copies were obviously addressed to Copernicus, who "saw his treatise only at his last breath on his dying day" – 24th May 1543, as reported by Tiedemann Giese in a letter to Rheticus that praised the young mathematician for his dedication to Copernicus's cause.

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[82] Several years after the publication of *De Revolutionibus*, Osiander himself admitted to Peter Apian to be the author of the section *Ad Lectorem*. Maestlin transcribed this note into his own copy of *De revolutionibus.* See J. Freely, *Celestial revolutionary*, p. 158.

[83] O. Gingerich, *The Book Nobody Read: Chasing the Revolutions of Nicolaus Copernicus* (New York: Walker & Company, 2004), pp. 389-422.

Giese's letter to Rheticus – dated 26th July 1543 – also mentioned a certain little treatise "by which you [sc. Rheticus] have skilfully vindicated [sc. the view] that the motion of the Earth is not contrary to the Holy Scriptures".[84] Since no copy of Rheticus's work was known to exist, for a long time Giese's reference remained uncorroborated. Only in the early 1970s did Reijer Hooykaas rediscover a text that dealt with the compatibility of the doctrine of the mobility of the Earth with the text of the Holy Scripture, attributing it to Copernicus' disciple.[85] In his *Letter on the motion of the Earth* (presumably written shortly after 1540) Rheticus argued that the Bible was intended only to teach what was necessary for salvation while on scientific matters it did not speak apodictically, rather adapting itself to the common way of speech or vulgar opinion. This work is crucial for understanding the role that the young mathematician played in advocating the acceptability of Copernicus's heliocentrism within the Catholic community of the time. It also gives ample evidence of Rheticus's great talent for innovative scholarly work, preceding as it did by many decades similar arguments made by Copernicans like Kepler, Foscarini, Lansberg, Wilkins, and Galileo.[86]

Rheticus's efforts to promote Copernicus's work did not cease with the publication of *De revolutionibus*. In 1550, seven years after his master's death, he published his *Ephemerides Novae*, a collection of tables in which he did not distance himself from the Copernican doctrine "not even by the width of a finger".[87] In the preface to his new publication, in the wake of his master, Rheticus stressed once again the necessity of expertise in astronomical matters, "so that even in our times the art can be completed". His message, however, went even further than this condition and conveyed an explicit request for collaboration between "the rich and powerful through expensive

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[84] K. H. Burmeister, *Georg Joachim Rhetikus, 1514-1574: Eine Bio-Bibliographie*, vol. III, p. 55.
[85] R. Hooykaas, "Rheticus's Lost Treatise on Holy Scripture and the Motion of the Earth", *JHA*, Vol. 15, Issue 2, 1984, pp. 77-80.
[86] T. Kirby, "The Cosmographic Mystery: Johannes Kepler's Conversion of Astronomy", *Laval Théologique et Philosophique*, Vol. 75 (1), Feb. 2019, pp. 59-74; I. A. Kelter, "A Catholic Theologian Responds to Copernicanism: The Theological 'Judicium' of Paolo Foscarini's 'Lettera'", *Renaissance and Reformation*, Vol. 21, No. 2 (1997), pp. 59-70; R Vermij, *The Calvinist Copernicans. The reception of the new astronomy in the Dutch Republic,* 1575-1750 (Koninklijke Nederlandse Akademie van Wetenschappen, Amsterdam, 2002), pp. 73-92; S. F. Mason, "Bishop John Wilkins, F.R.S. (1614-72): Analogies of Thought-Style in the Protestant Reformation and Early Modern Science", *Notes and Records of the Royal Society of London*, Vol. 46, No. 1 (Jan. 1992), pp. 1-21; E. Reeves, "Augustine and Galileo on Reading the Heavens", *Journal of the History of Ideas*, Vol. 52 (4), 1991, pp. 563–579.
[87] G. J. Rheticus, *Ephemerides Novae,* p. 290

undertakings, and the learned and erudite of astronomy in their laborious communications", because "this work is truly not the elaboration of one or a few, but was done with help and cooperation". By invoking "the generosity of Princes" and "the concords of the learned", Rheticus anticipated two important aspects underpinning the following development of modern science: patronage and the birth of a scientific community. His message was faithful to Copernicus' request for mathematical expertise, but it also pointed to a wider dissemination of his astronomical results – as testified by his involvement in the publication of his master's work.

At the end of 1573, thirty-five years after his first meeting with Copernicus, Rheticus met Lucius Valentin Otho, a young mathematician who in a short period became his closest disciple.[88] In his last work, Rheticus recalled their first encounter and highlighted the similarity with his own experience: "I was your age when I visited Copernicus" – exclaimed Rheticus. "Had it not been for my visit, his work would have never seen the printer".[89] Otho's presence was essential to the revival of Rheticus's mathematical ambition. During their time together the two mathematicians collaborated closely to perfect and revise a full set of tables used in angular astronomical measurement that Copernicus's disciple had elaborated in the previous decades. In autumn 1574, Otho was sent to Cracow – Rheticus's former residence – to collect some mathematical papers necessary to complete that work. This episode highlights the fact that Otho was not only a well-qualified mathematician but also a trusted disciple. Upon his return to Košice, however, on 4th December 1574 Rheticus died in his arms.

After Rheticus's death, paralleling his master's relationship with Copernicus, Otho was instrumental in completing and publishing the *Opus palatinum de triangulis* – a monumental work of 1500 pages of which more than 700 were tables – which extended *Canon doctrinæ triangulorum,* the pamphlet on trigonometric tables that Rheticus had published in 1551. In the preface to the *Opus palatinum,* Otho revealed that the *Dialogus* appended to Rheticus' *Canon* had convinced him

[88] E. Hilfstein, "Was Valentinus Otho a mathematics professor at the University of Heidelberg?", *Organon*, vol. 22-23,1986, pp. 221-225.
[89] G. J. Rheticus, V. Otho, *Opus Palatinum de triangulis* (Neustadt, 1596), f. b4v.

to pay a visit to its author. In that dialogue, indeed, Rheticus had stressed the importance of his relationship with his master by defining himself as "the one who is now bringing us this fruit from the delightful gardens of Copernicus". The closeness to Copernicus, whose fame was increasing throughout the Continent after the publication of *De revolutionibus*, was certainly a powerful reason to visit Rheticus. The relationship that the two mathematicians had been forged between the end of the 1530s and the beginning of the 1540s, had already become an exemplary model for the future generations of astronomers.[90]

Through the actions of both its critics and adherents, the publication of *De revolutionibus* in 1543 exerted major intellectual and disciplinary effects on the field of astronomy. By promoting a heliocentric view of the world, and by not merely offering a series of technical improvements to cosmology, Copernicus argued both that astronomers had a right to speak authoritatively in areas that had previously been the preserve of natural philosophers, and also that scholars required mathematical expertise if they were to speak credibly about the physical reality of the heavens. *Mathemata mathematicis scribuntur* became a rallying cry for later Copernicans, who explicitly acknowledged in this claim a sort of Pythagorean heritage. The phrase, and the pedagogical background to the book in which it appeared, also inaugurated a new template for the relationship between master and disciple, a structure that would constitute the foundations underpinning the successful transmission of specifically Copernican varieties of the "new philosophy". Without the meeting between Rheticus and Copernicus, the following history of science would have been different. As Adolf Müller put it, "without Rheticus we would know no Copernicus, without Copernicus no Kepler, without Kepler no Newton!".[91]

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[90] In 1628, the young astronomer Maarten van der Hove (Martinus Hortensius) began studying under Philippe van Landsberg, helping him to complete his scientific project. Landsberg later thanked Van den Hove publicly for the work he had done and said that he was lucky "that, by divine providence, in my old age, pressed by sickness, such a strong helper came to my aid, as formerly the learned Rheticus to the great Copernicus". P. van Landsberg, *Tabulae motuum coelestium perpetuae* (Middleburg, 1632), Preface.

[91] Adolf Müller, "Der Astronom und Mathematiker Georg Joachim Rheticus", *Vierteljahrsschrift für Geschichte und Landeskunde Vorarlbergs*, n. s., v. 2, (1918), pp. 5-46.

Rheticus had arrived in Frauenberg in 1538 as a visitor and left in 1541 as the first and only disciple of Copernicus. The significance of the pedagogical character of their relationship was stressed by Rheticus himself who, in his *Narratio Prima*, never referred to Copernicus by his name but always mentioned him as "*praeceptor meus"* (my teacher). Copernicus's theory as expressed in *De revolutionibus* was highly complex and required a technical training that only its author could provide. The fact that Copernicus overcame his renewed reluctance and agreed to share his astronomical secrets with Rheticus, however, underlines the fact that the latter was not just a pupil to instruct, but a trusted – and chosen – acolyte to proselytize. Mutual trust, indeed, was one of the main features of the relationship that they built: on the one hand, the master entrusted his most considerable results to a young mathematician that he had known just some weeks earlier; on the other hand, the disciple agreed to serve unconditionally his teacher and to champion his revolutionary cause.

The bond that the two mathematicians established in the short period of their contact went far beyond the pedagogical aspect: Copernicus passed on to Rheticus not only his knowledge but also his leadership. Shortly after its publication, the *Narratio prima* became authoritative and being the trusted disciple of such a master elevated Rheticus' stature. The disciple gained prestige by his previous proximity to the great author – he had the authority to say what Copernicus had really thought, said, or meant – and became a *primus inter pares* interpreter of a holy text. Copernicus benefitted from the interaction with the young disciple, too. The very existence of the *Narratio Prima* testifies that having worked with Rheticus impacted Copernicus's previous reluctance in publication. By accepting the growing importance of the print culture of his time, the Polish astronomer had eventually chosen to disseminate the core of his doctrine to a wider audience. Rheticus's work was probably intended as a first, circumspect test of its novelty, a *ballon d'essai*; eventually, it became the rehearsal of Copernicus's *De revolutionibus.*

CHAPTER 2

A "DISCIPLE OF MARS". JOHANNES KEPLER BETWEEN TYCHO BRAHE AND MICHAEL MAESTLIN

Tycho Brahe and the Copernican legacy

On 1st November 1575, during the coronation ceremony of Rudolph II as king of the Romans in Regensburg, the twenty-nine-year-old Tycho Brahe met Thaddeus Háyek, the personal physician of the future Holy Roman Emperor.[92] Brahe and Háyek shared a common interest in astronomy; in the previous years, indeed, they had both published a treatise on the famous *stella nova* that had appeared in the constellation of Cassiopeia in November 1572.[93] On that night, the two astronomers presumably conversed about that phenomenon, engaging in a discussion that gave birth to a frequent correspondence between them. In a letter dated 22nd March 1592, Brahe wrote to Háyek:

> From a letter recently sent to me by Dr. [sc. Johannes] Sager of Lübeck, I learned that Rheticus's library was bequeathed to you in his testament. If so, I ask you to have whatever concerns astronomy, whether he acquired it from his teacher Copernicus or by his own activity, copied at my expense and forwarded to me promptly.[94]

In the letters that followed, Háyek did not refer to Brahe's request nor did the Danish astronomer make any further mention of Rheticus's legacy to his interlocutor. It was only in Brahe's *Astronomiae instauratae progymnasmata* – written in 1588 and published posthumously in 1602 – that the author alluded to "a certain little treatise (*tractatulus*) by Copernicus", which was presented to him "in handwritten form some time ago at Regensburg by that most distinguished

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[92] An account of the meeting between Tycho Brahe and Thaddeus Háyek is given by E. Rosen, *Copernicus and his Successors* (London; Rio Grande: Hambledon Press, 1995), pp. 72-3.

[93] The two treatises in question are: Tycho Brahe, *De nova et nullius aevi memoria prius visa Stella, iam pridem Anno à nato Christo 1572, mense Novembrj primùm Constecta, contemplatio matematica*, (Hafniae, 1573); Tadeáš Hájek, *Dialexis de novae et prius incognitae stellae: inusitatae magnitudinis & splendidissimi luminis apparitione, & de eiusdem stellae vero loco constituendo*, (1574). Other astronomers wrote about the 1572 supernova: Wolfgang Schuler, Thomas Digges, John Dee, Francesco Maurolico, Jerónimo Muñoz, and Bartholomäus Reisacher.

[94] J. L. E. Dreyer (ed.), *Tychonis Brahe Dani opera omnia* (Copenhagen: Gyldendal, 1913-29), vol. VII, p. 333. In this letter, Tycho referred to Copernicus as Rheticus's *praeceptore.* Already in his *Astronomiae instauratae progymnasmata* (1588), the Danish astronomer had mentioned Rheticus as Copernicus's disciple.

man Thaddeus Hajek". "Subsequently", Brahe continued in his text, "I sent the treatise to certain other astronomers in Germany. I mention this fact to enable the persons into whose hands the manuscript comes to know its provenance".[95]

At the end of the 16th century, the circulation of manuscripts as a form of scribal publication that was disseminated alongside printed books and pamphlets was a very popular practice in the field of astronomy. Despite the fact that the publication of *De revolutionibus* had made Copernicus's work available to a wider audience, its forerunner, the *Commentariolus,* continued to circulate in the form in which it was originally designed by its author. The treatise was published in print only in 1878, from a copy that Longomontanus, one of Brahe's students, had presented to another of his pupils, Johannes Eriksen. Brahe's decision to circulate Copernicus's *Commentariolus* as a scribal publication acquires even more importance if we consider that the Danish astronomer had provided Uraniborg, his astronomical observatory, with its own printing press and a paper mill to supply it.[96] Moreover, it is worth mentioning that the copies realized and spread by Brahe were not anonymous like the ones that Copernicus had circulated a few decades earlier; moreover, although he was not a Copernican, the Danish astronomer nonetheless engaged with the dissemination of a work promoting the heliocentric system and its author.[97]

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[95] Tycho Brahe, *Astronomiae instauratae progymnasmata* (Uraniborg, 1610), part 2, see: *Tychonis Brahe Dani opera omnia*, vol. II, p. 428.

[96] During his life, Brahe was inclined to use both scribal publications – like letters and scripts – and printed artefacts to transmit his astronomical theories. In certain cases, he also combined the two forms. His work *Epistolae Astronomicae* (Uraniborg, 1596) represents a successful case of this kind: the work published the correspondence that Tycho had exchanged with the German Prince Landgrave Wilhelm IV of Hesse-Kassel and his mathematician and astronomer Christoph Rothmann. See A. Mosley, "Tycho Brahe's *Epistolae Astronomicae*: A Reappraisal", in T. van Houdt, *Self-presentation and social identification: the rhetoric and pragmatics of letter writing in early modern times* (Leuven: Leuven University Press, 2002), pp. 449–468.

[97] The title that Brahe devised for his copies of Copernicus's *Commentariolus* was *Nicolai Copernici de hypothesibus motuum coelestium à se constitutis commentariolus.* See N. M. Swerdlow, "The derivation and first draft of Copernicus's planetary theory: A translation of the Commentariolus with commentary", *Proceedings of the American Philosophical Society*, Vol. 117, No. 6, Dec. 31, 1973, pp. 413-512; T. Brahe, *Astronomiae instauratae progymnasmata*, part 2, in *Tychonis Brahe dani opera omnia* (Copenhagen, 1913-1929), vol. II, 428/34-40. J. Dobrzycki, L. Szczucki, "On the Transmission of Copernicus' Commentariolus in the Sixteenth Century", *Journal for the History of Astronomy*, Vol. 20, No. 1, 1989, pp. 25-28. G. Borski, M. Kokowski "Copernicus, his Latin style and comments to Commentariolus", *Studia Historiae Scientiarum,* 20, 2021, pp. 339–438; P. D. Omodeo, *Copernicus in the cultural debates of the Renaissance: reception, legacy, transformation* (Leiden; Boston: Brill, 2014).

Uraniborg represented the heart of the system devised by Tycho Brahe to produce and disseminate scientific knowledge. In 1576, when he founded its astronomical observatory and chemical laboratory thanks to the generous concession by the King of Denmark Frederick II, the Danish astronomer chose the best craftsmen and workers to build the infrastructure of his scientific realm, recruiting young scholars to train as scientific collaborators, assistants, and helpers.[98] Most of the students arriving at Hven – where Uraniborg was set – were Danes in their early twenties, while only a few short-term visitors came from Holland, Germany, and England. Most of the time, the students introduced themselves to Tycho via letters of recommendation by previous mentors from the university where they had already received a basic education. We cannot be sure about the criteria that Tycho used to recruit his students; we can nonetheless presume that a strong interest in astronomy was mandatory for selection. A background in mathematics was evidently desirable, since among the papers listing the students that visited Uraniborg, the name of a pupil called Sebastian was accompanied by a note specifying that he did not study mathematics, so as to highlight the exceptionality of that case.[99]

Once at Uraniborg, the students were trained again.[100] The education that the university of the time provided was far from the training that Tycho's research required for his assistants. In reference to Victorinus Schonfeld's son, who was about to go to Uraniborg in 1589, Tycho himself stated: "whether or not he has obtained the M.A. degree, is immaterial to me. […] It will suffice if he is a serious student."[101] The documents that survived at Uraniborg provide a glimpse of the main features of the students' apprenticeship at Hven. Firstly, Tycho believed that a three-year training regime was necessary to educate a skilled assistant. From a student notebook found in Copenhagen, we can infer that the pupils received some rudiments in spherical trigonometry, which constituted a

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[98] A loose paper found and preserved at the Royal Library of Copenhagen provides a glimpse of Brahe's first students and assistants on Hven. See J. L. E. Dreyer, *Tycho Brahe, a picture of scientific life and work in the sixteenth century* (Scotland: A. & C. Black, 1890), pp. 381-4.

99 V. E. Thoren, *The Lord of Uraniborg* (Cambridge University Press, 1991), p. 200.

[100] See J. R. Christianson, *On Tycho's Island: Tycho Brahe and his Assistants, 1570–1601*, (Cambridge University Press, 2000),

[101] J. L. E. Dreyer (ed.), *Tychonis Brahe Dani opera omnia*, VI, p. 198.

basic skill for astronomical computations. Presumably, mathematical ability was required only for advanced pupils while most of them received more practical training: the students were taught to use – possibly build – scientific instruments, to make observations, and to collect data.[102] Exactness, precision, and commitment[103] were strictly required as well as a good sense of teamwork.[104] Uraniborg was a complex system: everyone represented a critical piece of a complex mechanism and collaboration was essential.

Another important requirement on Hven was trust – imposed as a form of quasi-legal obligation. Tycho's collection of data took years of observations that demanded accuracy, integrity, and confidentiality. Anybody visiting Uraniborg was forbidden to reveal data taken from the observatory. This is emblematic of a declaration signed by Kepler on 5th April 1600 – and now preserved in the Hofbibliothek, Vienna – in which the German astronomer promised not to reveal Tycho's data without authorization.[105] It also underlies the events that followed the visit of Nicolaus Raimarus Ursus to Hven in 1584: after publishing an outline of his worldview in the *Fundamentum Astronomicum* (1588), the German astronomer was charged by Tycho of having derived his hypothesis by a defective diagram copied during his visit to Hven.[106] This episode opened a harsh priority dispute between the two astronomers, which involved some of Tycho's closest collaborators. It was one of Tycho's students at Helmsted who sent his master Ursus's *De astronomicis Hypothesibus* – a satirical and insulting work against Brahe; while between 1600 and 1601, Kepler was required to compose the *Apologia pro Tychone contra Ursum* as a condition for

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[102] In his *Somnium* – published posthumously in 1634 – Kepler recalled his time at Uraniborg and wrote: "I took a wonderful delight in the practice of astronomy. Brahe and his students watched the moon and constellations all night with marvelous instruments". E. Rosen, *Kepler's Somnium. The Dream, or Posthumous Work on Lunar Astronomy*, (University of Wisconsin Press: Madison, 1967).

[103] On one occasion, for example, Tycho lamented the negligence of one of his assistants: after his notation, which stated that the observation had been terminated by the onset of clouds, Tycho added the expression "and laziness". J. L. E. Dreyer (ed.), *Tychonis Brahe Dani opera omnia*, XII, p. 275.

[104] As V. E. Thoren conjectured, Tycho's observation presumably required a crew of three people: one to hold the lantern and read out sightings, another to sit by the log and make entries, and a third to stand by the clock and call out time as readings were recorded. See V. E. Thoren, *The Lord of Uraniborg,* p. 201.

[105] Similarly, half a century later Robert Boyle obliged his technicians to sign an oath document in which they declared faithfulness to their master. See S. Shapin, *A Social History of Truth* (University of Chicago press, 1995), pp. 355-407.

[106] N. Jardine, D. Launert, A. Segonds, A. Mosley, K. Tybjerg, "Tycho v. Ursus: The Build-up to a Trial, Part 1", *Journal for the history of astronomy*, 2005, 36 (1), p.81-106.

his appointment in Prague as Brahe's assistant.[107] This work was originally designed to vindicate Brahe and was focused on the analysis of Ursus's pronouncements on Brahe's geoheliocentric hypothesis.[108] In 1591, another episode of this kind had involved the Scottish mathematician Duncan Liddel, whom Tycho had accused of appropriation of his theory.[109]

Most of the students that visited Hven established with Brahe plain relationships of collaboration regulated by the channels of patronage. When they completed their service, they were dismissed and compensated with a letter by Tycho prestigious enough to launch new careers as parish priests somewhere in the provinces or to reach esteemed positions in other European universities.[110] Only a few students stayed at Uraniborg long enough to become Tycho's *famuli* – as he called the male members of his *familia*[111] – and only a few of them were then charged with the training of younger students arriving at Hven, since Tycho only occasionally oversaw their apprenticeship.

One of Tycho's most trusted collaborators was Peter Jacobsen Flemløse, who served the Danish astronomer for eleven years until 1588.[112] Flemløse's role at Hven was not confined to the

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[107] Nicholas Jardine, *The Birth of the History and Philosophy of Science. Kepler's 'A defence of Tycho against Ursus' with Essays on Its Provenance and Significance* (Cambridge, 1984). E. Rosen, *Three Imperial Mathematicians: Kepler Trapped between Tycho Brahe and Ursus* (New York: Abaris Books, 1986).

[108] While Kepler was assigned the task of refuting Ursus's critics to Tycho, Longomontanus (one of Tycho's closest collaborators) was asked to write an *apologia* against the Aristotelian arguments put forward by the Scottish physician and astronomer John Craig on the comet of 1577. See O. Gingerich, R. Westman, "The Wittich Connection: Conflict and Priority in Late Sixteenth-Century Cosmology", *Transactions of the American Philosophical Society,* vol. 78, 7, 1988.

[109] C. J. Schofield, *Tychonic and Semi-Tychonic World Systems* (New York, 1981), pp. 145–160. P. Omodeo, K. Friedrich (eds.), *Duncan Liddel (1561-1613). Networks of Polymathy and the Northern European Renaissance* (Leiden: Brill Academic Publishers, 2016).

[110] Cort Axelsen became professor of theology at the University of Copenhagen; Johannes Isaacsen Pontanus became a professor in Holland; Johannes Stephanius, became a professor at Copenhagen; Peter Jacobsen Flemløse became physician to the governor of Norway; Gellius Sascerides received a royal stipend to support his studies. No fewer than four of Tycho's students entered the Church and rose to the rank of bishop. On the importance of patronage in science during the early modern period see: J. R. Christianson, *On Tycho's Island: Tycho Brahe and his Assistants, 1570–1601*, pp. 25-27; M. Biagioli, *Galileo, Courtier: The Practice of Science in the Culture of Absolutism* (University of Chicago Press, 1994).

[111] Tycho used to refer to his entourage at Uraniborg with the Latin term *familia*, to indicate the unit of people who lived under his patriarchal authority. *Famulus* and *famula* were used respectively for male and female members. For a complete account of Brahe's network at Uraniborg see J. R. Christianson, *On Tycho's Island. Tycho Brahe, Science, and Culture in the Sixteenth Century* (Cambridge University Press, 2002), pp. 249-309.

[112] Before arriving at Hven, Flemløse had studied in Copenhagen and Leipzig where in 1574 he had attended Tycho's lectures on astronomy. At Uraniborg, Tycho had taught Flemløse to use scientific instruments like the cross-staff and the sextant, before charging him with compiling the new catalogue of reference stars for the 1577 comet. See V. E. Thoren, p. 134.

collection and elaboration of astronomical data; he was also responsible for the training of many young pupils like Elias Olsen Morsing.[113] In 1584 the latter was given the delicate mission of measuring with great accuracy the latitude of Frauenburg, the place where Copernicus had collected his astronomical data. Tycho established another significant bond with Frans Tengnagel, who served him for six years until 1601 on Hven, Wandsburg, and Bohemia before marring Tycho's daughter Elizabeth.[114] After the apprenticeship at Uraniborg, Tengnagel acquired some skills in astronomy though his chief expertise laid in politics. Indeed, between 1598 and 1599 he acted frequently as Tycho's ambassador for trips in Europe.

In 1589 Tycho met Christian Sørensen – better known as Longomontanus, a Danish student who served Tycho for eight years on Hven and two years in Bohemia. Presumably trained by Morsing, Longomontanus proved soon to be an outstanding observational astronomer. His skill at achieving ambitious astronomical results and the willingness that he showed in assisting Tycho's family, made him the most cherished acolyte.[115] Eventually he would have been Tycho's first choice in terms of succession but several circumstances – including his absence at Tycho's deathbed on 13th October 1601 – favoured for this role Johannes Kepler, who eventually inherited not only the title of Imperial Mathematician of the Holy Roman Emperor, Rudolph II, but also a priceless astronomical legacy.

Already acknowledged as an enterprising astronomer and superb mathematician, on 4th February 1600 Kepler arrived at Benátky castle, where Tycho had moved his astronomical observatory after the death of his protector Frederick II. Notwithstanding substantial astronomical divergences – Kepler was a convinced follower of Copernicus – their collaborative enterprise had a

[113] Elias Morsing stayed on Hven from 1583 to 1590. He was trained in Tycho's method of observation by Flemløse; in turn, he trained several assistants, including Rudolphus Groningensis and Hans Crol. See J. R. Christianson, *On Tycho's Island*, pp. 286-288.
[114] See also Christianson's detailed analysis of the wedding plans for Gellius Sascerides and Brahe's daughter Magdalene. J. R. Christianson, *On Tycho's island: Tycho Brahe, science, and culture in the sixteenth century* (Cambridge: Cambridge University Press, 2003), pp. 171-194.
[115] Longomontanus may have been the tutor of Tycho's sons. Moreover, he often accompanied them to Skåne to visit their grandparents. See J. R. Christianson, *On Tycho's Island*, pp. 281-285. H. Kragh, "Georgius Frommius (1605–1651) and Danish Astronomy in the Post-Tychonian Era", *Acta Baltica Historiae et Philosophiae Scientiarum*, 2015, 3, pp. 45-68.

great impact on the young German's work: firstly, he found in Tycho a patron whose support allowed him to leave the underpaid position at the Lutheran school of Graz; secondly, he inherited part of the huge and accurate collection of Tycho's data, which contributed significantly to the development of his astronomical discoveries; finally, he took up from Tycho the baton of an epistemological revolution that, begun by Copernicus, in a few decades would change radically the ways in which the discipline of astronomy and the astronomer's role were conceived.[116]

A traditional master and his extraordinary disciple

When Kepler arrived at Benátky castle in 1600 he had already published the *Mysterium Cosmographicum* (1596),[117] the astronomical treatise in which he provided for the first time his heliocentric representation of the celestial order demonstrated by means of geometrical arguments. The reception of Kepler's work was mostly critical: on the one hand, his heliocentric worldview elicited theological objections because of the discrepancy with passages in the Hebrew Bible (Old Testament) where the Sun was explicitly said to move; on the other hand, the introduction of physical reasoning into astronomy was not welcomed favourably by those who, instead, sought the foundations of astronomy in metaphysics rather than in physics. Notwithstanding the critics, Kepler's work nonetheless amazed many astronomers of the time, dazzled by the brilliant arguments that had led the young mathematician to his conclusions. These conclusions appear even more surprising if we consider that, at the time, Kepler was still highly motivated to pursue a theological career; this inclination, indeed, can be traced between the lines of his work.[118] The education he had received at Tübingen from 1589 to 1594 in this sense was crucial, since it had

[116] R. S. Westman, "The Astronomer's Role in the Sixteenth Century: A Preliminary Study".
[117] J. Kepler, *Prodromus dissertationum cosmographicarum, continens mysterium cosmographicum, de admirabili proportione orbium coelestium, de que causis coelorum numeri, magnitudinis, motuumque periodicorum genuinis & proprijs, demonstratum, per quinque regularia corpora geometrica - The Forerunner of Cosmographical Essays, Containing the Cosmographical Secret: On the Marvellous Proportion of the Celestial Spheres, and on the True and Particular Causes of the Number, Size, and Periodic Motions of the Heavens. Demonstrated by Means of the Five Regular Geometric Bodies* (Tübingen, 1596).
[118] P. Barker and B. R. Goldstein, "Theological Foundations of Kepler's Astronomy", *Osiris*, Vol. 16, Science in Theistic Contexts*: Cognitive* Dimensions (2001), pp. 88-113.

been reformed in line with the religious and political changes that the whole Continent was experiencing after the Reformation.[119]

Philipp Melanchthon was a leader in effecting the pedagogical revision that followed the Reformation: in a few years, he systematized the university *curricula* and institutionalised a scholarly tradition that lasted at least one century. Proficiency in the *humanae litterae*, the study of the liberal arts, and familiarity with the Biblical languages (Latin, Ancient Greek, and Hebrew) were the pillars of a reformation in which every intellectual activity was subordinated to Lutheran exegesis. If the recognition of God was the aim of the pursuit, the mathematical sciences – especially astronomy – represented the means to achieve it. In his project, Melanchthon emphasised the religious and pedagogical value of astronomy as a form of contemplation of the divine creation and promoted the study of the heavens through arithmetic and geometry, "wings of human minds".[120] Mathematical astronomy became a curricular discipline, and its teaching was secured in all the centres that adhered to the Melanchthonian academic reform.

Concerning the content of the teaching, the students' *curricula* were still anchored to the Aristotelian philosophical corpus, though this reliance did not imply a strict adherence to a rigid body of doctrines.[121] In astronomy, Melanchthon chose traditional textbooks like Sacrobosco's *De sphaera Mundi* – which he edited with his own introduction – while an important role was assigned to astrology, which was considered as the science of divine Providence. The teaching of Copernicanism as a philosophical view was strictly forbidden; the heliocentric theory was allowed only as a technical device. In a remark to the professors, indeed, Melanchthon specified:

> Although subtle practitioners take into consideration many [sc. different hypotheses] in order to exercise their intellects, nonetheless the youth should know that they [sc. the practitioners] do not dare to affirm such theories. In their first education, [sc. students] shall appreciate opinions transmitted with the shared consensus of the practitioners, which are minimally absurd. If [sc. students] grasp that truth is manifested by God, they will embrace this with reverence and be satisfied with it.[122]

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[119] C. Methuen, *Kepler's Tübingen: Stimulus to a Theological Mathematics* (UK: Ashgate Publishing, 1998).
[120] With this expression Melanchthon supported the use of mathematics in the inquiry of nature. See P. Melanchthon, "In arithmeticem praefatio Georgii Ioachimi Rhetici", in Carolus Gottlieb Bretschneide (ed.), *Philippi Melanthonis Opera quae supersunt omnia* (Halis Saxonum, apud C.A. Schwetschke et filium, 1843), vol. 11, p. 288.
[121] R. S. Westman, "The Melanchthon Circle, Rheticus, and the Wittenberg Interpretation of the Copernican Theory", *Isis*, Vol. 66, No. 2 (Jun., 1975), pp. 164-193.
122 P. Melanchthon, *Initia doctrinae physicae* (Leipzig 1563), f. 31v.

The strict line adopted against the teaching of Copernicanism was eased only when the debates on planetary modelling and hypotheses culminated in the development of a system that translated the heliocentric view into a geocentric cosmology – i.e., the Tychonic system. Students were then allowed to defend little variations of that model in their astronomical disputations. This opening, however, did not allow professors to disseminate new philosophical and scientific theories to their students.[123]

A massive recruitment of Lutheran astronomers and mathematicians completed Melanchthon's reformation; in a few years Germany became "the nursery of mathematics".[124] Among others, Michael Maestlin took part in this project. He studied theology, mathematics, and astronomy at the Lutheran University of Tübingen where he received his *magister artium* in August 1571. Then, after a brief period at the University of Heidelberg, he came back to Tübingen in 1584 to replace the well-known astronomer Philipp Apian – Peter Apian's son and Maestlin's master – as professor of mathematics and astronomy. In mathematical classes, Maestlin taught his students Euclidean geometry and elements of trigonometry, while in astronomy he used a textbook that he wrote in 1572, the *Epitome Astronomiae*, in which he explained and commented on the geocentric world system as described in Ptolemy's *Almagest*.[125] In accordance with the institutional guidelines, the Copernican theory – which Maestlin had first met in 1570 when, still a student, he had bought a

[123] Still in the 1650s, the mathematician Johannes Placentinus was warned by the University of Frankfurt an der Oder – where he was just appointed professor – with a clear note: "He [sc. Placentinus] should abandon all opinions differing from the genre of philosophy that is accepted in our [university]. In the case that he adheres to some new doctrines, he should keep them to himself and renounce disseminating them among the students." P. D. Omodeo, "Institutionalised Metaphysics of Astronomy at Early Modern Melanchthonian Universities", in H. von E. Cancik-Kirschbaum, A. Traninger (ed.), *Wissen in Bewegung. Institution – Iteration – Transfer* (Wiesbaden: Harrassowitz, 2015), pp. 51-78.
[124] P. Ramus, "Scholae Physicae, Praefatio", in P. Ramus*, Scholae in liberales artes. Basileae,* per Eusebium Episcopium et Nicolai F. haeredes (Basileae,1569). Westman in his essay *The Astronomer's Role* claims that the increase of mathematical chairs between 1530 and 1560 in Germany, justified the much larger circulation of Copernicus's *De revolutionibus* in that area than in any other part of Europe. The technicalities contained in the Pole's astronomical treatise, in fact, allowed only expert mathematicians to cope with the book.
[125] M. Maestlin, *Epitome astronomiae qua brevi explicatione omnia, tam ad sphaericam quam theoricam eius partem pertinentia, ex ipsus scientie fontibus deducta, perspicue per quaestiones traduntur*. The first edition was published by Jacob Mylius in Heidelberg in 1582. The textbook went then into six further editions, all published in Tübingen between 1588 and 1624. It is worth underlining that between 1617 and 1621 Kepler published a treatise with a similar title (*Epitome Astronomiae Copenicanae Usitata forma Quaestionum & Responsionum conscripta, inque VII. Libros digesta quorum Tres hi priores sunt de Doctrina Sphaerica*) in which, in contrast to his master, he sustained the Copernican heliocentric system. On Maestlin's teaching see C. Methuen, "Maestlin's Teaching of Copernicus: The Evidence of His University Textbook and Disputations," *Isis*, Vol. 87, No. 2 (Jun., 1996), pp. 230-247.

copy of the first edition of *De Revolutionibus*[126] – was still banned. Despite such a restriction, Maestlin, a convinced Copernican, nonetheless often mentioned the prohibited heliocentrism in his lectures, as testified by one of his students:

> Six years ago, when I was studying under the distinguished Master Michael Maestlin at Tübingen, I was disturbed by the many difficulties of the usual conception of the universe and I was delighted by Copernicus, whom Mr. Maestlin often mentioned in his lectures.[127]

The author of these words was Johann Kepler, who in the preface to the *Mysterium Cosmographicum* – as in many other occasions throughout his life – remarked on the intellectual debt he owed towards his "distinguished Master". Maestlin, indeed, had not only provided his promising student with a good mathematical and astronomical background; he had also inspired him to write a tract – the *Mysterium Cosmographicum* – which championed the Copernican theory.

Although Kepler began to write the *Mysterium Cosmographicum* at Tübingen under Maestlin, most of the work was conducted in Graz where, after graduating, he had obtained a position as teacher of mathematics at the Protestant school. At Graz, Kepler exchanged a copious correspondence with Maestlin in which they discussed the content of his work and the editorial choices related to its publication.[128] Kepler asked his master for advice; Maestlin replied with comments and suggestions, like the inclusion of further illustrations to the main text "because without a diagram the thing is without question most obscure".[129] Maestlin advised that clarity of ideas was essential for presenting such an innovative work, and in accordance with Matthias Hafenreffer – the Pro-rector of the University of Tübingen whose academic senate had approved the publication of the book – he also advised his student to supply the *Mysterium Cosmographicum*

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[126] On 6 July 1570 Maestlin bought his copy of *De Revolutionibus* "from the widow of D. D. Victorinus Strigelius, sister of D. Theodore Snepfius". This edition with many commentaries is in Schaffhausen: doi:10.3931/e-rara-79844. See R. S. Westman, "Three Responses to the Copernican Theory: Johannes Praetorius, Tycho Brahe, and Michael Maestlin", in *The Copernican Achievement*, ed. R. S. Westman (Berkeley and Los Angeles: University of California Press, 1975), pp. 285-345.

[127] Johannes Kepler, *Mysterium Cosmographicum - The Secret of the Universe*, translation by A.M. Duncan, Norwalk: Abaris Books, 1999, *Praefatio*, p. 63.

[128] The two mostly communicated about Kepler's editorial project through correspondence. They met personally only once, at the beginning of 1596, when Kepler left Graz for a journey to his homeland. On that occasion, they discussed the completion and publication of the book. See A. Grafton, "Michael Maestlin's Account of Copernican Planetary Theory", *Proceedings of the American Philosophical Society*, vol. 117, no. 6, 1973, pp. 523–50).

[129] *Johannes Kepler Gesammelte Werke* (Munich, 1937), vol. XIII, p. 85. Hereafter mentioned as *KGW*.

with an introduction defending Copernicus's hypothesis as well as his appeal to the five Platonic solids as inscribed polyhedra representing the exact distances of the planets from each other. Kepler agreed to that proposal and suggested adding Rheticus's *Narratio Prima*, too.[130] This idea, however, was refused by Hafenreffer who claimed that Rheticus's work was too long and, in some ways, irrelevant to Kepler's matter.

Eventually, Kepler's book was printed with both an introduction to Copernicus – the first chapter of the *Mysterium* – and Rheticus's *Narratio Prima* as an appendix. The latter, moreover, was preceded with a preface by Maestlin in which the German professor explained (for the first time publicly) the reasons for his own adherence to Copernicanism.[131] In this instance, the master spoke through his disciple's work. It is interesting to note that Maestlin authored his preface to the *Narratio* without Kepler's approval; only on 15th November 1596, when the *Mysterium* was already in print, did he reveal to his erstwhile student his responsibility for that unexpected inclusion:

> I also added, unknown and unconsulted by you, Rheticus's *Narratio*, revised by me, and an augmentation of a diagram, together with my preface; it is now starting to go to press, with the last of all your notes. I hope however it will not be shameful to you.[132]

The reason that moved Kepler and Maestlin to propose that insertion – and to force its inclusion as an appendix – is explained in the *Mysterium*, when Kepler stated that if he had read the *Narratio Prima* earlier, the labour that he had undertaken to compare the Copernican and the Ptolemaic systems would not have been necessary. This explains the value that both master and disciple attributed to Rheticus's work: the *Narratio* not only introduced *De Revolutionibus*; it also explained more clearly some passages that in Copernicus's own account were obscure and difficult to

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[130] See K. A Tredwell, "Michael Maestlin and the Fate of the Narratio Prima", *Journal for the History of Astronomy*, 35, 2004, pp. 305-25.

[131] Before the publication of Kepler's *Mysterium Cosmographicum*, Maestlin had never been so explicit concerning his Copernican conviction. See M. Bucciantini, *Galileo e Keplero. Filosofia, cosmologia e teologia nell'Era della Controriforma* (Einaudi: Torino, 2003), pp. 12-17.

[132] *KGW*, vol. XIII, p. 95. In his preface – and in two further letters – Maestlin justified his decision: Rheticus's *Narratio* was essential to mathematical practitioners for understanding Kepler's *Mysterium*. An account of Maestlin's interest in reprinting and commenting Rheticus's *Narratio Prima* is given by K. A. Tredwell, "Michael Maestlin and the Fate of the Narratio Prima", *Journal for the History of Astronomy*, August 2004, Vol.35(3), pp. 305-325.

understand. Also, it represented a vehicle to nurture the ongoing debates concerning the new cosmology.

Kepler welcomed favourably Maestlin's unexpected addition to his work, and in 1621 he allowed his master to include Rheticus's work in the second edition of his *Mysterium cosmographicum* and to add an updated version of his preface. Besides this direct intervention, Maestlin also contributed indirectly to shaping his disciple's text. Kepler, indeed, did not possess his own copy of *De revolutionibus* until 1595; it is likely that in the process of writing, he consulted his master's copy. In this way, he not only had direct access to Copernicus's word but the privilege of consulting Maestlin's copious marginal notes and comments to the text. Kepler himself highlighted this intellectual collaboration when, in addressing his master, he wrote:

> I have but slight basis to call it my work. In the origin of this work I was Semele, you Jupiter. Or if you would rather compare the work with Minerva than with Bacchus, then I as Jupiter carried it in my head. But if you had not performed the midwife's task as Vulcan with the axe, I should never have given birth.[133]

When the editorial work was completed, Maestlin arranged for the publication of the book. As he wrote to Kepler in his frequent missives, he went to the printing press two or three times per day to supervise the operation personally – a commitment that had obliged him to postpone a work on the Gregorian calendar he had been commissioned to write. The *Mysterium cosmographicum* was printed in 1596 and, in the spring of 1597, its author received the first copy. The book was then ready to be distributed and, once again, Maestlin was actively involved by Kepler's side in its promotion. In this case, and indeed throughout their relationship, it is not always clear who was master and who was not.

Print culture, mathematical expertise, and Pythagoras

The analysis of the dissemination of Kepler's *Mysterium Cosmographicum* requires an important preliminary remark: at the time, publishing a book did not imply its wide and

[133] Kepler to Maestlin, 10 February 1597. *KGW*, vol. XIII, p. 105.

uncontrolled distribution. Even if printed, books circulated in ways not too different from manuscripts. Of course, print publication allowed many more people to enter in contact with a fixed and not alterable text. But authors continued to be directly involved in spreading their works and, so, in choosing the audience that they wanted to address. Besides, it is important to note that publication was not strictly linked to commercial enterprises, and even when it was, the authors still supervised closely the distribution of their books.[134] When the printing of the *Mysterium Cosmographicum* was concluded, most of the copies were sent with a cover letter to a selected readership which included Tycho Brahe, Galileo Galilei, Reimarus Ursus, and Georg Limnaeus.[135] Kepler received from the printer 200 copies of his own book and prepared as many letters for the addressees; 50 copies were also given to Maestlin, who was crucial for the broad dissemination of his student's work.

The letters that accompanied Kepler's book were not one-way tickets. As is clear from a missive that Kepler sent to Galileo on 13th October 1597, the author explicitly asked his correspondents for their judgements on his work: "this is my way to urge all those to whom I have written to express their candid opinion. Believe me, the sharper criticism of one single understanding man means much more to me than the thoughtless applauses of the great masses".[136] Thus, Kepler did not aim at spreading his work as widely as possible to acquire approbation from the *hoi polloi*; rather, he desired to receive *iudicia incorrupta* only from skilled mathematicians, with the ultimate purpose of establishing the Copernican system as the predominant worldview.

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[134] A good account on the authorship, production, distribution, and reception of astronomical books in the Early Modern age is given by A. Mosley, "Astronomical books and courtly communication," in *Books and the sciences in history,* ed. M. Frasca-Spada and N. Jardine (Cambridge: Cambridge University Press, 2000), pp. 114-131.

[135] In the second edition of his *Mysterium Cosmographicum* (1621) Kepler referred to the fact that after the publication of the 1596 edition he received favourable letters from those mathematicians who, presumably, received the book by the author himself. We also know that the book was sent to Johannes Praetorius and Helisaeus Roeslin, who, anchored to anti-Copernican positions, harshly criticized Kepler's astronomical theories – although we have scant evidence on Kepler's awareness of those critiques. On the reception of the *Mysterium Cosmographicum*, see J. R. Voelkel, *The composition of Kepler's Astronomia nova* (Oxford: Princeton University Press, 2001), pp. 60-91.

[136] Kepler to Galileo, 13 October 1597. In *KGW*, vol. XIII, pp. 144-146.

What follows in that letter to Galileo, reveals the strategy Kepler had designed for that "divine" purpose:[137]

> For there are not only your Italians who cannot believe that they are being moved if they do not sense it, but also we here in Germany do not win the greatest favour with this doctrine. But there are reasons for which we should defend ourselves against these difficulties. First, I am separated from that vast multitude of men, and I do not take in the din of so many shouts at once. Besides, those who are near me are a crowd of men who, although they do not grasp these abstruse things, as they say, are nevertheless astonished, and do not ever think for themselves whether they want to believe or not. The moderately learned ones, the more knowledgeable they are, the more cautiously they involve themselves in these disputes of mathematicians. And furthermore they can be bewitched – I say this because I speak from experience – by the authority of those skilled in the mathematical arts, so that when they hear that we now have ephemerides constructed from Copernicus's hypotheses, [sc. they believe that] everyone who now writes ephemerides follows Copernicus, and if it is demanded of them that they grant that it cannot be demonstrated except in mathematical principles, [sc. they believe] the phenomena cannot agree without the motion of the earth. For though these postulates or pronouncements are not credible in themselves, still they are to be granted by non-mathematicians; and although they are true, why should they not be passed off as irrefutable? Therefore only mathematicians remain, with whom this is done with greater effort. Since they have the same profession they do not concede postulates without a demonstration. Of these the more ignorant one is, the more difficulty he causes.

Then, he continues:

> Nevertheless, also here a remedy can be furnished: isolation. There is one mathematician in any place; where it is so, it is the best. Then if he has a sharer of ideas somewhere else, he should obtain a letter from him for this reason: when the letter has been exhibited (to which end yours is also of use to me) it can incite this idea in the minds of the learned, as if all professors of mathematics everywhere agreed.

In the first part, Kepler delineates the cultural context of his time: firstly, he mentioned the crowd (*vulgus hominum*) that, unable to grasp abstruse things, could be led to the truth only by the appeal to the *auctoritates*; then, he referred to the "moderately learned ones" who, usually prudent towards mathematical disputes, could nonetheless be enthralled by those skilled in the mathematical arts; finally, Kepler referred to the mathematicians, who never conceded *postulata sine demonstratione*. The mathematicians could be divided into two categories: the *imperitior* (the unskilled) and the *peritior* (the skilled). The former had to be avoided because the more ignorant

[137] We should always have in mind that in publishing his work Kepler was moved by religious reasons. On 3*rd* October 1595, he wrote to Maestlin: "I am eager to publish (my observations) soon, not in my interest, my dear teacher […] I strive to publish them in God's honour who wishes to be recognized from the book of nature. […] For a long time I was restless: but now see how God is, by my endeavours, also glorified in astronomy". See G. Graßhoff, "Michael Maestlin's Mystery: Theory Building with Diagrams", *Journal for the History of Astronomy*, 43(1), February 2012, pp. 57-73. The truth of the Copernican system was a manifestation of God and a sign of its divine design; the astronomers were "priests of the highest God in regard to the book of nature". C. Baumgardt, *Johannes Kepler: Life and Letters* (London: Victor Gollancz LTD, 1952), p. 31.

they were, the more difficulties they caused; the latter – among which Kepler included both himself and Galileo – were the only scholars capable of understanding the Copernican doctrine and accepting the arguments in its favour. So, in the second part, Kepler delineated a strategy to reach this purpose: building a community of expert mathematicians – the most expert – and using their correspondence to show to the men of learning the unanimous agreement on the Copernican system. In this way, heliocentrism would become unchallengeable.

Kepler's strategy as delineated in the letter to Galileo echoes the Copernican motto "mathemata mathematicis scribuntur"; like the Polish astronomer, indeed, Kepler was appealing to a sort of mathematical expertise not only for dealing with astronomical questions but also for determining their truth. Ultimately, his requirement can be understood as a form of Pythagorean elitism – and its related practice of being silent and surreptitious with the amorphous crowd in order to share knowledge only with the few skilled mathematicians – at least in a preliminary phase. The following year, Kepler's reference to Pythagoras became more explicit when, on 6th January 1598, he wrote to Maestlin: "Although it is already late I begin to praise the silence of Pythagoras and the obscurity of Plato".[138] And, again, on June of that same year, he stated:

> Since the majority of scholars cannot rise to the high conception of Copernicus, well now, we shall imitate the Pythagoreans also in their customs. If someone asks us for our opinion in private, then we wish to analyse our theory clearly for him. In public, though, we wish to be silent.[139]

These passages indicate an enhanced version of the previous strategy expressed to Galileo. Perhaps the intellectual situation of the time had a role in making Kepler cautious in expressing openly the Copernican theory; or perhaps it was more the caution of his patron – in this case the rector of the University of Tübingen – to nourish his worry.[140] Kepler only cared about constructive critics –

[138] Kepler to Maestlin, 6 January 1598. *KGW*, vol. XIII, p. 165.
[139] Kepler to Maestlin, 11 June 1598. *KGW*, vol. XIII, p. 231.
[140] The rector Matthias Hafenreffer sent a letter to Kepler expressing "the brotherly advice by no means to support and defend that agreement openly; for many good people would take offense, and not unjustly, and your entire work could be entirely hampered or else burdened with the grievous reproach of having created disunity". M. Caspar, *Kepler,* p. 68.

favourable or not – to his work.[141] On 9th August 1610, indeed, another important reference to Pythagoras confirms his position: after the publication of Galileo's *Sidereus Nuncius*, in a letter addressed to the Italian mathematician, Kepler praised the "wise Pythagoras, who believed that the majesty of philosophy is present in nothing but silence. But now the die is cast." – he continued – "You, my Galileo, have opened the holy of the holiest of the skies. What else can you do but despise the noise which has been created."[142]

Kepler's reference to Pythagoras did not represent a mere suggestion but an exemplary model to revamp in order to shape the new scientific community of modern science. Compared to Copernicus, however, his novelty consists in the way in which he conjoined this strategy with the new role that the printing culture was acquiring in communicating scientific knowledge.[143] In concluding the preface of the *Mysterium Cosmographicum*, Kepler justified his "haste" in publishing the book by referring to a vow he had made to God while at work: at the first opportunity he would have proclaimed "among men in public print this wonderful example of His wisdom". Thus, when the work was "approved by Maestlin the celebrated mathematician" he was bound to his vow and could not "oblige the satirist who tells us to delay books for nine years". Before Kepler, this Horatian rhetorical device had been used by Copernicus in the preface of *De Revolutionibus*; in that case, however, the Polish astronomer actually delayed the publication of his masterpiece "not merely until the ninth year but by now the fourth period of nine years". Kepler, on the contrary, seems to be moved by an uncontrollable enthusiasm in sharing his astronomical results with other "powerful talents" of his time. His confidence in printing is also testified by a passage of *De stella nova in pede serpentarii, et qui sub ejus exortum de novo iniit, Trigono Igneo* (1606) in which the author recognized the benefits that this invention had had in every field of knowledge –

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[141] In a letter to the Chancellor Herwart von Hohenburg Kepler wrote: "Solicit the judgments of mathematicians known to you about my newly published little book, no matter how favourable to me, and have them sent to me (if I do not ask presumptuously) on your authority." Kepler to Herwart, 12 September 1597, in *KGW*, vol. XIII, p. 132.
[142] Kepler to Galileo, *KGW*, vol. XVI, p. 323.
[143] J. Kepler, *Mysterium Cosmographicum*, translation by A.M. Duncan (Norwalk: Abaris Books, 1999), p.69; R. S. Westman, "Proof, poetics and patronage: Copernicus' preface to De Revolutionibus", in D. C. Lindberg, R. S. Westman, *Reappraisals of the Scientific Revolution* (Cambridge University Press, 1990), pp. 167-206.

astronomy included: “After the birth of printing, books became widespread. […] Every year, especially since 1563, the number of writings published in every field is greater than all those produced in the past thousand years. Through them there has today been created a new theology and a new jurisprudence; the Paracelsians have created medicine anew and the Copernicans have created astronomy anew”.[144]

By resorting to printed books to spread his theories, Kepler was meeting the changes of his age; at the same time, however, he was not breaking completely with the tradition of addressing a chosen audience of skilled mathematicians. This position is confirmed by a note that Kepler wrote at Linz in 1619 after the publication of his *Harmonices Mundi*, the *Admonitio ad bibliopolas exetero, praesertim Italos* (*Recommendation to foreign book dealers, especially Italian*), in which he made a specific request to the bookdealers:

> You bookdealers, it is true, will act according to law and order, if, considering the given judgment, you will not openly offer copies of my book for sale. But you must realize that you have to serve philosophy and the good writers, so to speak, as “notaries”, who must provide the judges with the written defence. Therefore, please, sell the book only to the highest clergy, the most important philosophers, the experienced mathematicians and the profoundest metaphysicians, to whom I, personally, as the advocate of Copernicus have no other approach. These may decide whether it is only the fabrications of eccentric imagination which are at issue or whether it is something which can be verified by evident facts as the result of the investigation of nature. These men may decide whether one should make these immeasurable beauties of the divine works known to the common people or rather diminish their glory and suppress them by censures.[145]

Although print culture made his books accessible to everyone, Kepler nonetheless continued to believe in the necessity of mathematical – and philosophical – expertise in order to uphold the Copernican truth “as legitimate and unassailable”.

The idea of mathematics as superior knowledge that only a few expert mathematicians could cope with emerges in another aspect of Kepler’s enterprise: both the style of his works and the mathematical techniques that he applied to astronomy rendered his texts inaccessible to the amorphous crowd. It is not uncommon among his readers to find complaints about the

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[144] J. Kepler, *De stella nova* (1606), *KGW*, vol. I, pp. 330-2.
[145] *KGW*, vol. XI, pp. 543-44.

difficulties of deciphering such technicalities.[146] On 6th February 1610, for example, the mathematician William Lower expressed his thoughts concerning Kepler's *Astronomia Nova* to his teacher Thomas Harriot, who had sent him the book: although Lower had read the text twice, he nonetheless found it too arduous to understand – but, at the same time, intensely stimulating.[147] Some years later, Kepler's *Epitome Astronomiae Copernicanae* (1621) provoked a similar reaction in Peter Crüger, Professor of Mathematics at Danzig, who in 1622 wrote to Philip Müller, Professor of Mathematics at Leipzig University:

> I have received the 4th book of Kepler's astronomy [...] I have read more than once what he says about the proportion of the orbits and the planetary bodies in the places referred to by you. The Poet says that to read a thing ten times is pleasing. But this work I do not yet understand after reading it a hundred times. The author seems, as usual, to obscure the matter deliberately. However, I will study all these things later at leisure with my whole strength, though I do not see what use this will be.[148]

The unfamiliarity of most mathematicians of that time with the properties of ellipses combined with the alleged willingness of the author "to obscure the matter deliberately", rendered Kepler's works almost unreadable – or, at least, unintelligible. As the correspondence of his readers shows, the comprehension of certain technicalities required support and collaboration – especially for the youngest mathematicians who usually asked their masters' help. Besides, the role of a mathematician of the time was strictly related to didactic purposes, even when the master-disciple relationship took place outside the traditional institutional contexts. Disciples helped with calculations and observations; in return, they learned mathematical techniques and astronomical theories.

An unconventional master

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[146] On the reception of Kepler's theories see J. L. Russell, "Kepler's Laws of Planetary Motion: 1609-1666", in *The British Journal for the History of Science*, Vol. 2, No. 1 (Jun., 1964), pp. 1-24.

[147] "Indeed, I am so much delighted with his booke, but he is so tough in manie places as I cannot bite him. I pray write me some instructions in your next, how I may deale with him to ouermaster him for I am readie to take paines". The letter is published in in H. Stevens, *Thomas Hariot: the Mathematician, the Philosopher, and the Scholar* (London: Privately printed, 1900), pp. 120-I24.

[148] W. Dyck and M. Caspar, *Nova Kepleriana 4: Die Keplerbriefe auf der Nationalbibliothek und auf der Sternwarte in Paris. Abhandlungen der Bayerischen Akademie der Wissenshaften. Mathematisch-naturwissenschaftliche. Abteilung. XXXI* (München: Verlag der Bayerischen Akademie der Wissenschaften, 1927), p. 107.

Kepler was a master both inside and outside the institutional context. His first teaching experience began in 1594 at the protestant school of Graz, whose inspectors initially appeared uncertain about his capacity for the role: "We have talked with him as much as necessary and have formed the opinion that we sincerely hope he will be able to succeed the late Master Studius nobly. Yet we wish to try him out for one or two months before we hire him on a permanent basis."[149] After one year, however, the young mathematician had earned their trust: Kepler "distinguished himself first as a speaker [perorando], then as a teacher [docendo] and finally as a debater [disputando], in such a manner that we cannot judge otherwise than that he was, considering his youth, a well-trained and modest master and professor, and one who fitted well into this worthy district school".[150] The inspectors' words acquire even more value if we consider that Kepler had very few listeners during his first year of teaching and none during the second, "because the study of mathematics is not everyone's meat".[151]

Studying mathematics required receptiveness, enthusiasm, and, in some ways, devotion. Only a few pupils were inclined to dedicate their lives to the mathematical sciences and even less were talented enough to undertake that study. Moreover, Kepler's expectation of his students was very high. The students' objective difficulty in learning mathematics, combined with Kepler's economic situation – which obliged him to move from place to place in search of financial stability – made his relationships with other young mathematicians more collaborative than hierarchical. At the beginning of the 17th century, he found in some of Tycho's assistants friendly collaborators to share and improve his astronomical results via regular correspondence. Then, wherever he went, he recruited young mathematicians to train as assistants. Kepler established with most of them a relationship based on the master-disciple model: firstly, he instructed his students in the Copernican

[149] M. Caspar, *Kepler* (New York: Dover, 1993), p. 56.
[150] *Ibid.*, p. 57.
[151] This is a sentence by the inspectors' report. See *KGW*, vol. XIX, p. 8.

system; then, he instructed them to collect data and draw up ephemerides. These relationships extended outside the academic context and were regulated by financial agreements.[152]

Benjamin Ursinus and Janus Gringalletus were two of Kepler's most important collaborators. The former assisted Kepler until 1614, firstly in Prague, then in Linz; three years later, the latter arrived in Linz through the Strasbourg physician Florian Crusius and remained by Kepler's side until 1620. Their interaction with Kepler was of the greatest importance for the development of his astronomical work and shows that Kepler not only required mathematically skilled helpers but also expected his assistants to be open-minded enough to acknowledge mathematical novelties such as the logarithm. This discovery was propounded by the Scottish mathematician John Napier in 1614 with the publication of the book *Mirifici Logarithmorum Canonis Descriptio* (*Description of the Wonderful Rule of Logarithms*). As Kepler reported in a letter addressed to Napier and published in the *Ephemeris* for 1620, he was introduced to the discovery of logarithms by his assistant Ursinus; then, thanks to Gringalletus, he proved mathematically those functions and, convinced by their utility, he decided to use them to construct his ephemeris.[153] In those years collecting data was essential and the use of logarithms became a precious ally for astronomical calculations: near the end of 1623, indeed, Kepler completed the star catalogue he had begun in 1600 with Tycho Brahe. Named after the Holy Roman Emperor Rudolph II, the *Tabulae Rudolphinae* included planetary tables based on the heliocentric model with elliptical orbits; logarithms were used to simplify the calculations and to render them more accurate.

The help of Ursinus and Gringalletus as assistants was essential to Kepler to refine and complete a work that represented an outstanding result for the accuracy of the data collected,

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[152] In Prague he was close to Ambrosius Rhode, a German mathematician, astronomer, and physician who assisted Tycho in his observations. Another important relationship was established with Philipp Müller, the Leipzig professor who corresponded with Kepler for a long time.

[153] In the letter addressed to Napier, referring to Napier's book Kepler said: "I was not able to read it through until last year when I stumbled upon a book by Benjamin Ursinus, for a long time an assistant of my household, now astronomer to the Margrave (in which he gave a brief summary copied from your book) which is why a know about it […] Then, with the help of Janus Gringalletus Sabaudud, an assistant of mine, I ordered him to subtract the thousandth part of the whole sine, to subtract again a thousandth part from the remainder, and to do that more than two thousand times, until there should remain about the tenth part of the whole sine". For the English translation of the letter see B. Rice; E. González-Velasco; A. Corrigan, *The Life and Works of John Napier* (Switzerland: Springer, 2017), pp. 958-960.

making it an indispensable tool for seventeenth-century astronomers. The difficulties underlying the production of the *Tabulae Rudolphinae*, however, did not cease with their publication; the chaotic situation caused by the Thirty Years War, combined with Kepler's lack of money, delayed the edition of the book, which took four more years to come into light. Eventually, the publication was arranged in Ulm, where the text left the press in September 1627. Once again, Kepler decided to send some copies to his trusted friends: one volume "still hot from the press", for example, was addressed to a young promising mathematician whose name, Jacob Bartsch, appeared also inside the volume. Bartsch was born in Luban (now southern Poland) in 1600. Before meeting Kepler, he received a varied education that combined elements of astronomy, rudiments of mathematics, and medicine. In his *Usus astonomicus planisphaerii stellati* (Strasbourg, 1624), Bartsch expressed his gratitude toward his previous teachers Sarcephalus and Philipp Müller. The former, mathematician and librarian at Wroclaw, had introduced him to the astrolabe, while the latter was mentioned as "the most excellent professor of mathematics at Leipzig university". In 1621, Bartsch left Leipzig and transferred to the University of Strasbourg where he enrolled as a student of medicine, before moving again to Padua to continue his studies. When Kepler sent Bartsch a copy of the *Tabulae* in 1627 they barely knew each other, but in a few years they became very close both professionally and personally.[154]

The first contact between master and future disciple happened in April 1625, when Bartsch sent to Kepler a copy of his tract *Novus globus coelestis* (Strasbourg, 1624) in which he described the celestial globe that he and his brother Frederick had built the previous year. In the letter that accompanied the tract, Bartsch asked for Kepler's comments on his work, and then added: "I should like nothing better than to hear it from you in person".[155] Kepler welcomed favourably Bartsch's request and met him in Ulm in that same year.[156] The arrangement of that encounter highlights the

[154] See E. Rosen, *Kepler's Somnium. The Dream, or Posthumous Work on Lunar Astronomy*, Appendix A, pp. 177-193; J. A. Connor, *Kepler's Witch* (Harper Collins, 2004).
[155] *KGW*, Vol. XVIII, pp. 232-36.
[156] In a letter dated 1628, Bartsch recalled that first meeting with Kepler. See E. Rosen, *Kepler's Somnium*, p. 180.

first reciprocal choice between master and disciple and signals the beginning of their relationship: on the one hand, Kepler was presumably intrigued by Bartsch's text, so much so that he decided to meet its young and still unknown author to discuss its content. On the other hand, it is worth noting that Bartsch's admiration for Kepler motivated him to send a copy of his text to the German astronomer as a probe or a gift; at that time, Kepler was considered a leading mathematician on the Continent and his name was vastly esteemed, especially among Copernicus's followers.

The first meeting between Kepler and Bartsch was successful: a few months later, indeed, the former mentioned Bartsch in the Preface of his *Tabulae Rudolphinae*, describing him as "a diligent young man, who some time ago acquired an excellent reputation for his good work in connection with the celestial globe".[157] When a copy of Kepler's work arrived in Augsburg where Bartsch lived, it was accompanied by a letter in which Kepler invited the young astronomer to read carefully the text and to ask questions about its content. Bartsch accepted Kepler's request, and at the beginning of 1628 the text was returned to its author followed by several letters; as Kepler put it, Bartsch "did not neglect the opportunity to ask questions everywhere". We can interpret this exchange in two ways: firstly, as long-distance teaching – Bartsch asked questions that Kepler answered with clarifications and explications; secondly, the keen inquiries of a smart and talented mathematician challenged the master. So, the exchange benefitted both scholars, and contributed to the establishment of a closer relationship.

The correspondence between Kepler and Bartsch from 1628 onwards deserves a special mention. At the time, Kepler was moving from place to place in search of financial support, with the consequence that such mobility made him difficult to reach. Bartsch sent copies of his letters to a number of different addresses such as Prague and Ulm, but either the letters came back to the addressee, or they remained unanswered. Bartsch solved that logistic problem with a brilliant solution: he published his message to Kepler in the form of an open letter as one of the prefaces that

[157] *Ibid.*

preceded his *Ephemerides* for 1629. In receiving Bartsch's text, Kepler would also receive his letter. Kepler was presumably thrilled by the solution of a student that he praised as a "brilliant and assiduous" disciple;[158] although he had the chance to meet Bartsch at Zagan on 26th July 1628 to discuss the content of his letters face to face, he nonetheless decided to publish his answer to Bartsch publicly. Kepler's reply announced his association with that talented disciple: "you, my dear Bartsch, offered me your cooperation long ago in the letter that you sent from Augsburg to Ulm, and now in your public letter. I publicly acknowledge with pleasure that at our recent meeting I accepted your cooperation".[159] That message was just the prelude to an increasingly closer relationship.

In 1629, in the wake of Tycho Brahe's model, Kepler decided to strengthen his association with Bartsch still further. With the help of one of his dearest friends, the German philologist and professor of history at the University of Strasbourg Matthias Bernegger, Kepler planned to nourish his professional bond with Bartsch by fostering the wedding of the young mathematician to one of his own daughters, Susanna.[160] The exchange of letters between Kepler and Bernegger concerning this issue is copious and helps to highlight interesting details about Kepler's intentions: although he was firmly convinced about Bartsch's talent as a mathematician, he was nonetheless concerned about Bartsch's anchoring his studies to astrology. Exhorted by his friend, Bernegger prepared a letter to be sent to Bartsch in which he wrote:

> In your letter to me and also in the ephemeris [sc. for 1629] which, to our great honour, you dedicated to us [sc. the faculty of Strasbourg University], I noticed that you are a close friend of Kepler. If you listen to me, you will bind him even more closely to yourself by a family relationship. He has a marriageable daughter, whom I have never seen, but she is well known to me through the letters which we have exchanged.[161]

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[158] In his *Ephemerides* for 1629-36, Kepler addressed Wallenstein, duke of Friedland and dedicatee of the work, by saying: "The first happy outcome of my moving to Silesia as a result of your generosity, o famous duke, was that in neighbouring Lusatia I found a brilliant and assiduous colleague in continuing the work on the Ephemerides". *KGW*, Vol. XI, 1, p. 504.
[159] C. Frisch (ed), *Johannes Kepleri astronomi opera omnia* (Frankfurt: Erlangen, 1858), vol. VII, p. 584.
[160] On the implications of these social relationship in science see: G. Algazi, "Exemplum and Wundertier. Three Concepts of the Scholarly Persona", *Low Countries Historical Review*, 131:4 (2016), pp. 8–32; G. Algazi, "Scholars in Households: Refiguring the Learned Habitus, 1480–1550", *Science in Context,* 16:1-2 (2003), pp. 9–42.
[161] E. Rosen, *Kepler's Somnium*, pp. 186-187.

Becoming Kepler's son-in-law, Bernegger continued, would be a sign of great "distinction and no small satisfaction", and he added that Bartsch "should bear in mind that someday you will inherit those true treasures of mathematics. To be sure, the great man does not keep you away from them even now, as they are open doors to the Muses. Still we may believe that he will reveal them to you much more freely if you bind yourself to him in this relationship".[162] This passage underlines once again Kepler's attitude in revealing the "true treasures of mathematics" only to trusted people and shows that the notion of binding – the term used for an apprentice tying himself to the employ and tutelage of a master – was extremely relevant to the situation.

Eventually, Bernnegger's letter was not approved by Kepler, who decided not to exercise such pressure over Bartsch; nonetheless, the young mathematician proposed in September 1629 and, after six months, on 12th March 1630 he married Susanna Kepler. What followed in the story reveals Kepler's long-sightedness: just one week before the wedding, thanks to Kepler's patronage, Bartsch was designated professor of mathematics at the University of Strasbourg. Such an ambitious position was not compensated by salary because it did not involve any teaching, but it was nonetheless ideal for Bartsch who did not reside in Strasbourg and worked instead by Kepler's side in Zagan. There, the two of them continued their work on the composition of logarithmic tables: Kepler elaborated them; Bartsch refined his result. Their complicity while working was exemplary and would have brought extraordinary astronomical and mathematical outcomes. In November 1630, however, Kepler unexpectedly died.

This tragic event did not break the bond between Kepler and Bartsch; on the contrary, it confirmed Bartsch's loyalty toward the German astronomer. As a member of the family, Bartsch took care of the dramatic economic situation that Kepler had created during his last trip to Leipzig, when, after drying up all his family's money, he also borrowed 50 guldens from a merchant – it was Bartsch who paid off Kepler's debts. On the other hand, as a faithful associate, Bartsch carried on

[162] *Ibid.*

Kepler's work: he completed the new logarithmic tables and arranged the publication of Kepler's *Somnium seu Astronomia Lunari* (*Dream or Astronomy of the Moon*). Kepler's *Somnium* began as a student dissertation defending the Copernican doctrine when the German astronomer was a student at Tübingen (1593). During his life, the author revisited the main draft several times, adding to the original text the dream framework and a series of explanatory notes reflecting the different stages of both his intellectual development and his real life. Besides its intriguing plot and scientific relevance, indeed, the *Somnium* represented Kepler's personal and professional legacy. Unfortunately, Bartsch did not live enough to handle the publication of Kepler's last book – he died prematurely in 1633. The editorial operations were completed only in 1634 by Kepler's son, Ludwig, who inherited his father's manuscripts and made them available to the next generation of astronomers.

Kepler's story is emblematic of the revolutionary age he was living in. Not only was he contributing to the establishment of a new system of the world; by replacing the secular figure of the astronomer *calculator* with the "philosophizing astronomer",[163] he was also actively participating in the reformation of the astronomer's role. The computational skills required to astronomers to predict phenomena until the 16th century were no longer enough: astronomy was becoming increasingly linked to natural philosophy, and mathematical expertise was essential for understanding the physical reality of the world. In this context, educating young mathematicians acquired crucial importance.

Tycho Brahe established an exemplary model in this sense. His scientific realm, Uraniborg, constituted the first attempt to create a scientific community in which the collaboration of young tyros played a crucial role to the efficiency of the whole system. Among the huge number of students that visited Hven, only a few of them – the most trusted and presumably the most skilled –

[163] Kepler defined the astronomer's new figure in *Apologia Tyconis contra Ursus*, redacted in 1600 but published for the first time in 1858 in *Johannes Kepleri astronomi opera omnia*, C. Frisch (ed) (Frankfurt: Erlangen, 1858), Vol I p. 247.

were admitted to the inner circle of Tycho's collaborators. Their special *status* was not only linked to the important duties that Tycho assigned to them but also to their affinity with him and to their proximity to his family. Uraniborg, besides, constituted a unique setting: the inhabitants of the island – students included – worked closely not only to achieve ambitious scientific projects but also to fulfil the needs of a quasi-self-sufficient structure. Such a model was very different from the academic context in which Kepler was educated; it nonetheless had a relevant impact in the way in which he built his relationships with collaborators, assistants, and disciples.

Maestlin's tutoring of Kepler at Tübingen reflected the standard version of the master-disciple relationship born within the institutional context: Kepler chose Maestlin as a master because he was fascinated by his astronomical view – especially the heliocentric theory – and its underpinning values. Maestlin, on the other hand, accepted the commitment of such a brilliant student because he saw in Kepler's clientage a way of continuing the Pythagorean-heliocentric cult to which he belonged. The reciprocal choice was followed by a period of close interaction, which strengthened a relationship that continued beyond the borders – physical and intellectual – of the academic environment. The revision, publication, and dissemination of Kepler's *Mysterium Cosmographicum* highlights the importance of a mentor that followed each phase of his disciple's first editorial operation. Maestlin, on the other hand, seized the opportunity to spread his unorthodox views through the voice of that uninhibited disciple.

Contrary to Maestlin, Kepler never accepted the strict institutional obligations imposed by the academic context of his time and as a master acted quite unconventionally. Operating outside the university setting, he never established traditional master-disciple relationships with younger mathematicians: every assistant that he recruited – Ursinus, Gringalletus, and even Bartsch – was paid for his work, sometimes generously.[164] In another important sense, however, we can discern in Kepler's collaborators the disciple's main traits: they recognized Kepler's authority as a master in

[164] In a letter to Müller, Bartsch stated: "I don't want to refuse to collaborate with Kepler. Besides other promises, which are far from negligible, he pays no small sum for the work". *KGW*, Vol. XVIII, p. 395.

both mathematics and astronomy; they strongly believed in his cause and in the world system that he was trying to promote; they helped and supported their master in developing and spreading his ideas. Although we cannot use fixed schemes to identify Kepler's helpers, we can nonetheless say that the German mathematician established important relationships that contributed not only to the development of his work but also to the creation of a circle of experts, as envisaged in the letter to Galileo (1597).

Whether Kepler reached his goal or not is difficult to state. What we can say, however, is that in the wake of Copernicus he fought as a "disciple of Mars" to promote astronomy as deeply rooted in the mathematical field.[165] For Kepler mathematics was something more and beyond mere calculations: it required trained experts who could share theoretical views and the passion for innovation. The institution of close relationships shaped on the master-disciple model represented the privileged channel for passing on that new kind of scientific knowledge and for establishing the truth of Copernicanism.

[165] In a missive to Philipp Müller dated October 1629, Kepler defined himself as a "disciple of Mars". This expression referred to his intellectual and logistic efforts to promote the new astronomy and innovation in mathematics within the tense atmosphere of the Thirty Years war. See *KGW*, Vol. XVIII, p. 408.

CHAPTER 3

THE "GALILEAN SECT":

TALENTED MATHEMATICIANS, DEVOTED DISCIPLES

Mathematics before Galileo: Christopher Clavius and the Ratio studiorum

From the late 15th century onwards, mathematics was acquiring more and more importance as the fundament of all the sciences, provoking increasingly heated disputes on the nature of its study and on the certainty of its demonstrative method. The *quaestio de certitudine mathematicarum* – as the dispute was named – was discussed by two main factions of intellectuals. On the one hand, in the wake of Alessandro Piccolomini, Aristotelian philosophers and logicians denied to mathematics the status of science: mathematics referred to quantity in abstract and not in relation to physical realities, and thus it did not provide scientific knowledge. On the other hand, an opposite position was defended by mathematicians like Francesco Barozzi who, inspired by Proclus's *Commentary* on the first book of Euclid's *Elements*, believed that Euclid's demonstrative method could be made compatible with Aristotle's logic.[166]

In association with the existence of arguments concerning the certainty to which mathematical demonstrations could reach, there were serious debates concerning the utility of mathematical approaches to natural philosophy. The often fierce division over this question divided philosophers and mathematicians in the most important academic centres of the time, and involved institutions such as the Jesuit order, which had emerged during the religious and political tensions experienced with the Reformation.[167] In this context, the position taken up by mathematicians like Christopher

[166] On these themes see A. De Pace, *Le matematiche e il mondo: ricerche su un dibattito in Italia nella seconda metà del Cinquecento* (Milano: Franco Angeli, 1993); M. Feingold (ed.), *The New Science and Jesuit Science: Seventeenth Century Perspectives* (Dordrecht: Kluwer Academic Publishers, 2003); A. Scaglione, *The liberal arts and the Jesuit college system* (Amsterdam: John Benjamins Pub. Co., 1986); M. Biagioli, "The Social Status of Italian Mathematicians, 1450–1600", *History of Science*, 27 (1991), pp41-95; P. Mancosu, *Philosophy of Mathematics and Mathematical Practice in the Seventeenth Century* (Oxford University Press, 1996).

[167] Ch. B. Schmitt, "Philosophy and Science in Sixteenth-Century Universities. Some Preliminary Comments", in J.E. Murdoch, E.D. Sylla (eds.), *The Cultural Context of Medieval Learning* (Dordrecht: Reidel, 1975), pp. 485-530; Ch. B. Schmitt, *Filosofia e Scienza nel Rinascimento* (Firenze: La Nuova Italia, 2011), pp. 153-192.

Clavius, who supported the study of mathematics as indispensable for the inquiry of nature, became more acceptable.[168] According to Clavius, mathematical procedures stemmed from the "*pulcherrimo naturae ordine*" (the most beautiful order of nature), so they were not only appropriate to explain the physical world, but also indispensable for understanding it.

Clavius played a central role in the reformation of the study of mathematics within the Jesuit order. During the second half of the 16th century, he edited several works that contributed to the advancement of that discipline both within and outside the university. In 1574 he published a translation of the *Elements of Euclid,* while a few years later he wrote a commentary on Sacrobosco's *De Sphera* which, during the following decades, became one of the most influential astronomy textbooks of the time – between 1570 and 1618 Clavius's text went through at least sixteen editions.[169] Besides these contributions, during his time at the Collegio Romano Clavius played a key role indrafting the *Ratio Studiorum,* an important document that concerned administrative norms, curricular guidelines, and pedagogical procedures. That document contributed not only to shaping the new active role of the *mathematicus*, but also to opening a constructive debate on the epistemological status of mathematics.[170]

Although the definitive version of the *Ratio Studiorum* was promulgated in 1599, its composition had begun already in 1584, when the General Father of the Jesuit order, Claudio Acquaviva, had summoned to Rome a team of Jesuit scholars to discuss the project. Two drafts followed that gathering, one in 1586 and the other in 1591; after several meetings and many revisions, on the eve of the new century, the final version of the document was ready to be circulated. Clavius's name was mentioned on the various drafts of the *Ratio studiorum* – a fact that testifies to his active

[168] Christopher Clavius (1538-1612) was a Jesuit mathematician and astronomer. His talent for the mathematical studies made of him the "Euclid of the sixteenth century", as his contemporaries called him. He was also involved in the reform of the calendar under Pope Gregory XIII. See U. Baldini (ed.), *Christoph Clavius e l'attività scientifica dei Gesuiti nell'età di Galileo* (Roma: Bulzoni, 1995).

[169] Clavius's major works include: *In Sphaeram Iannis de Sacro Bosco commentaries* (1581); *Astrolabium* (1593); *Geometria practica* (1604); *Algebra* (1608); *Triangula spherical* (1611); *Opera mathematica* V tomis distributa (1611-1612). See C. Clavius, *Christophori Clavii Opera mathematica V tomis distribunt* (Moguntiae: sumptibus Antonii Hierat, excudebat Reinhard Eltz, 1611-1612).

[170] D. C. Smolarski, "Teaching Mathematics in the Seventeenth and Twenty-First Centuries", *Mathematics Magazine*, Vol. 75, No. 4 (Oct., 2002), pp. 256-262.

involvement in the project. If that proof was not enough, moreover, we could trace his contribution between the lines of the text, especially in the matter of mathematics. Most of the suggestions included in the document, indeed, reflected ideas that he had already expressed in his previous treatises.

One of Clavius's most important achievements concerned the institution of a course that provided students with an appropriate training in the mathematical sciences. In terms of pedagogy, the *Ratio studiorum* suggested a list of classical texts to adopt; these included Euclid,[171] the *Spherical elements* of Theodosius, the *Conics* of Apollonius, and Archimedes's works. It also introduced practical pedagogical activities such as presentation[172] and repetition[173] to exercise and enhance the students' skills. In this way, the students received a proper education that provided them with a profound understanding of the importance of mathematics in a wide range of disciplines, including poetry, history, politics, metaphysics, theology, law, and medicine. From the surviving documentation we also know that Clavius suggested the creation of an "academy" where expert masters could educate the most talented students in advanced mathematics. This ambitious proposal – already expressed by the Jesuit father in his *Modus quo disciplinae mathematicae in scolis Societatis possent promoveri* (1582) – was included in the first two drafts of the *Ratio Studiorum*. However, it did not appear in its final version, in which the "mathematical academy" was reduced to "private lessons".[174]

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[171] S. Rommevaux, *Clavius: une clé pour Euclide au XVIe siècle* (Paris: Libr. philosophique J. Vrin, 2005), pp. 13-29.

[172] "Once or twice a month, let someone of the students explain in detail some famous mathematical problem before a large gathering of students of philosophy and theology, after first having been taught it thoroughly by the teacher, as necessary". L. Lukács, *Monumenta Pædagogica Societatis Iesu, Vol. V: Ratio atque Institutio Studiorum Societatis Iesu* (Rome, Institutum Historicum Societatis Iesu, 1992), p. 402. English translation by D. C. Smolarski, "Teaching Mathematics in the Seventeenth and Twenty-first Centuries", p. 259.

[173] "Once a month and generally on Saturday in place of the lecture, let the principal points that have been explained during that month be publicly repeated". L. Lukács, *Monumenta Pædagogica Societatis Iesu*, p. 403. English translation by D. C. Smolarski, "Teaching Mathematics in the Seventeenth and Twenty-first Centuries", p. 260.

[174] Although it was not approved by the commission, Clavius's proposal for the creation of a school specializing in mathematical studies was realized in 1611 by François d'Aguilon in Antwerp. In 1617, Clavius's pupil Grégoire de Saint-Vincent began teaching in that school. His works on mathematics are considered the "clearest early account of the summation of geometric series." See C. Naux, "*L'Opus geometricum* de Grégoire de Saint-Vincent", *Revue d'Histoire des Sciences et de Leurs Applications*, 1962, Vol.15, pp.95-104; M. E. Baron, *The Origins of Infinitesimal Calculus* (Oxford: Pergamon Press, 1969).

The *Ratio studiorum* not only concerned the students' curricula; it also regulated the role of the professors of mathematics within the academic community and their relationship with other scholars.[175] The *mathematicus* was strongly encouraged to have a more active role within the academic milieu, for example by participating in public disputes during formal ceremonies, for

> by this it will easily come about that the pupils, seeing the professors of mathematics together with the other teachers taking part in such acts and sometimes also disputing, will be convinced that philosophy and mathematical science are connected as they truly are; especially because pupils up to now seem almost to have despised these sciences for the simple reason they think that they are not considered of value and are even useless, since the person who teaches them is never summoned to public acts with the other professors.[176]

A sharp note was addressed to the instructors of philosophy, who in their lectures often denigrated mathematics and considered it as a non-science. On the contrary, "because of their ignorance of mathematical science, some professors of philosophy very often committed many errors, and those most grave; and what is worse they have even committed them to writings some of which it would not be difficult to bring forward".[177] On this point, the 1591 draft of the *Ratio Studiorum* explicitly enjoined the school administrators to persuade the instructors of philosophy not to disparage mathematics and mathematicians.[178]

Dignifying mathematics as a science and binding it to the study of natural philosophy was of the greatest importance for Clavius. With his work, the Jesuit mathematician proposed a complete and complex strategy to initiate a radical change in attitude and structures. He wanted to make sure that Jesuit schools, then beginning to be founded in various parts of Europe, would give proper

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[175] R. Moscheo, *I Gesuiti e le matematiche nel secolo XVI. Maurolico, Clavio e l'esperienza siciliana* (Messina, 1998); R. Gatto, "Cristoforo Clavio e l'insegnamento delle matematiche nella Compagnia di Gesù", in A. Clericuzio, G. Ernst, M. Conforti (eds.), *Il Rinascimento italiano e l'Europa* 5° vol. *Le scienze* (Treviso-Costabissara 2008), pp. 437-54; D. C. Smolarski, "Jesuit Ratio Studiorum, Christopher Clavius and the Study of Mathematical Sciences in Universities", *Science in Context*, Vol. 15, no. 3 (Autumn 2002), p. 447-457; M. Feingold, *The new science and Jesuit science: seventeenth century perspectives* (Dordrecht: Kluwer, 2003); M. Feingold, *Jesuit Science and the Republic of Letters*, (Cambridge: The MIT Press, 2003); L. Ingaliso, "Tra vetera et nova: per una definizione del paradigma scientifico dei Gesuiti nel XVII secolo", *Galilaeana*, a. 2 (2005), pp. 253-275; A. Udías, *Jesuit contribution to science: a history*, (Cham: Springer, 2015).

[176] A. C. Crombie, "Mathematics and Platonism in the sixteenth century Italian universities and in the Jesuit educational policy", in Y. Maeyama, W. G. Saltzer (eds), *Prismata: Naturwissenschaftsgeschichtliche Studien* (Wiesbaden, 1977), pp. 63-94.

[177] R. Westman, "The Astronomer's Role in the Sixteenth Century: A Preliminary Survey", *History of Science*, 1980, Vol.18(2), pp.105-147, p. 132.

[178] L. Lukács, *Monumenta Pædagogica Societatis Iesu,* p. 236.

prominence to the study of mathematics. The emphasis on this discipline, besides, came at a crucial time. The Italian milieu needed to build a strong community of mathematicians to create a favourable environment and to nurture new developments, but also to keep up with other European countries where mathematics was emerging as indispensable to the study of nature. The *Ratio studiorum* in this sense represented a remarkable achievement: although it was not designed to overturn the peripatetic barriers – on the contrary, it was conceived to reconcile Aristotle with mathematics – it nonetheless helped to open a debate on the importance of mathematics as a science, the regulation of its study – at least inside the Jesuit schools, and its relation to philosophy.

A polymathic education

Reconciling mathematics with philosophy – and mathematicians with philosophers – was not the only challenge that Italian natural philosophers had to face by the end of the 16th century. This disciplinary gap, indeed, had one of its main causes in a fracture existing within the discipline of mathematics itself, namely that between "celestial" and "terrestrial" mathematics.[179] The former was traditionally taught in universities by professors of astronomy or astrology to prepare future physicians; the latter – which included land surveying, engineering, hydrostatics, and cartography – was practised inside the abacus schools, established at the beginning of the thirteenth century by the Pisan mathematician Leonardo Fibonacci.[180] Those two institutions taught different kinds of mathematics in terms of purposes, methods, subjects, languages of teaching, choices of texts, intellectual traditions, and status; consequently, they trained two different kinds of mathematicians. It was in this context that Galileo Galilei received his education; by combining those traditions he would ultimately contribute to their reconciliation.

After receiving basic education at the ancient monastery of Vallombrosa (near Florence), and encouraged by his father Vincenzo, on 5th September 1580 Galileo matriculated at the Arts Faculty

[179]M. Biagioli, "The Social Status of Italian Mathematicians, 1450–1600", *History of Science*, 27, (1990), pp. 41-95.
[180] R. Franci, L. Toti Rigatelli, "Towards a History of Algebra from Leonardo of Pisa to Luca Pacioli", *Janus*, vol. 72, 1985, pp. 17-82.

of the Studio Pisano where he began to study medicine. Soon it became clear that he would not become a physician, but his increasing interest in mathematics was not fulfilled by the university professors of the time, loyal to the most conservative Aristotelian philosophy. From 1583, Galileo gradually moved away from university to study mathematics with the private tutor Ostilio Ricci.

The first meeting between Galileo and Ricci was described differently by Galileo's first biographers Vincenzo Viviani and Niccolò Gherardini.[181] According to the former, Galileo begged his father Vincenzo to allow the family friend Ricci to instruct him in mathematics. The latter's version, instead, is more compelling: it narrates the story of a young Galileo who secretly attended Ricci's lectures on Euclid – at the time, Ricci was in Pisa with the Tuscan court as instructor of the grand-ducal pages and only members of the court were allowed to attend his lessons. Inspired by such lectures, Galileo fervently sought a copy of Euclid's *Elements* and studied it on his own, before approaching the master to ask for clarifications. Enthralled by hearing such a talented boy, Ricci was curious to know who his teacher was; Galileo replied that he had no other teacher but the one who was questioning him. Beyond the reliability of both these anecdotes – which were almost certainly embellished by his biographers – it is important to stress a peculiar feature of Gherardini's tale, which highlights a relevant aspect of the birth of the master-disciple relationship, namely the presence of reciprocal choice. After recognizing Galileo's talent, Ricci chose to be his master; likewise, Galileo had chosen to address Ricci after hearing his lessons. After this, a period of close personal contact followed, which resulted in a period of profound interaction and exchange.

What kind of education did Galileo receive from Ricci? Answering this question requires a preliminary understanding of Ricci's role within the learned community of his time. In 1583, when he met Galileo, Ricci was already attached to the Grand Duchy of Tuscany as the instructor of the court pages; in three years, however, he became a court mathematician.[182] Thus, his status was neither

[181] In 1654 Leopoldo de' Medici asked Vincenzo Viviani and Niccolò Gherardini to write each an account of Galileo's life. The two outlines should have been part of an unrealized larger biography of Galileo. Viviani and Gherardini's works were published posthumously in 1717 and 1780 respectively.

[182] At that time the role of the court mathematician was mainly associated with military engineering; Ricci's skills in military architecture, for example, were required to build a fortification for the Island of Iff (outside the port of Marseille).

attached to "celestial mathematics" – mainly taught in universities – nor was it entirely defined by the main features of "terrestrial mathematics". Several clues, nevertheless, indicate that he was closer to the latter tradition than to the former. Ricci's proximity to the world of the "technicians" is evidenced by his direct and frequent interaction with them: besides his position at the Tuscan Court, he was master of perspective in the "bottega" (workshop) of the Florentine artist, architect, military engineer, urbanist, and miniaturist Bernardo Buontalenti. In 1593, moreover, Ricci's association with the practitioners was institutionalized by his membership of the *Academia del Disegno*, where he instructed artists, sculptors, and architects.[183]

Another important clue that connects Ricci to the tradition of the abacus schools consists in the fact that he owned of a copy of Leon Battista Alberti's *Ludi Mathematici.*[184] Written between 1450 and 1452, that pedagogical treatise proposed several problems of practical geometry – like the measurement of distances, heights, and depths – in the form of *ludi* (games).[185] In his study on the subject, Tom Settle confirms that Ricci adopted this text for pedagogical purposes; thus, it is likely that Galileo studied it. Ricci's employment of the *Ludi matematici* reveals an important feature of his pedagogy: his choice of language for teaching mathematics. Instead of using Latin, as was usual in universities, Ricci used the vernacular, as was customary in the abacus schools. This aspect is relevant for understanding the nature of Galileo's mathematical training. Besides the *Ludi matematici*, in fact,

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See M. Biagioli, "The Social Status of Italian Mathematicians, 1450–1600", pp. 45-46; T. B. Settle, "Ostilio Ricci, a bridge between Alberti and Galileo", in *XII Congrès International d'Histoire des Science*, Actes, Paris, 1971, III B, pp. 121–126.

[183] The *Accademia del disegno* was a technical school founded by Giorgio Vasari in 1563 to promote art not only as an artistic manifestation but also as a discipline involving theoretical and technical knowledge. The educational program included the study of disciplines like anatomy, mathematics, mechanics, architecture, perspective, and music. See Z. Wazbinski, *L'Accademia Medicea del Disegno a Firenze nel Cinquecento, Idea e Istitutione* (Firenze: L.S. Olschki, 1987); L. Olschki, "L'Accademia Fiorentina del Disegno nella Storia delle Arti e delle Scienze", *Nuova Antologia: Rivista di Lettere, Scienze ed Arti*, 1926, 61, 470-479; K. E. Barzman, *The Florentine Academy and the Early Modern State. The Discipline of 'Disegno'* (Cambridge: Cambridge University Press, 2000).

[184] The manuscript owned by Ricci is preserved at the *Galileiana collection* of the Biblioteca Nazionale Centrale of Florence. On this subject see T. B. Settle, "Ostilio Ricci, a bridge between Alberti and Galileo", *Actes du XIIe Congrès International d'Histoire des Sciences* (Paris, 1971) pp. 121-126; K. Williams, L. March, and S. R. Wassell (ed.), *The mathematical works of Leon Battista Alberti* (New York: Springer, 2010).

[185] The practice of using *ludi* in mathematics had ancient roots. In the Middle Ages, this tradition was recovered and revived as a pedagogical technique to introduce young students to the study of mathematics. Niccolò Tartaglia's *Trattato di numeri et misure* (1556–60), for example, is shaped in this form.

the master might have also recommended to Galileo an Italian translation of Euclid's *Elements* by Niccolò Tartaglia[186] published in 1543 and reprinted cheaply in 1565.[187]

Studying Euclid at this early stage of his education was for Galileo of the greatest importance because it shaped both his mathematical skills and his belief in the broad ontological and epistemic significance of mathematics. We should have in mind that the algebraic notation was still alien to late-Renaissance mathematics. The only way to analyse physical events through mathematics was by means of proportions, as established by the Greek mathematician Eudoxus and used in book V of Euclid's *Elements.* In Galileo's view, proportion represented a relationship of similarity between two ratios formed by homogeneous quantities, as no ratios were possible between heterogeneous quantities – a concept based on Euclid's notion of equimultiple proportionality.[188] The Euclidean theory of proportions was assumed very early by Galileo as the language of his new mathematical physics; in the last stage of his life, moreover, he pushed this assumption even further and in the fifth day of his *Discorsi* (published posthumously through the efforts of trusted disciples) he reconceptualised Euclid's theory and replaced it with his own version.[189]

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[186] Tartaglia had plausibly been Ricci's master, although on their relationship there is no agreement between scholars: L. Geymonat argues that Ricci was a direct pupil of Tartaglia, whereas Stillman Drake claims that Ricci was the one who introduced Galileo to the study of Archimedes and Euclid by using Tartaglia's editions, without presuming a pedagogical association between the two mathematicians. See A. Presas i Puig, *Ostilio Ricci, The Practical Education and the Canon of Technical Knowledge at the Beginning of the Italian Renaissance* (Berlin: Max Planck Institut für Wissenschaftsgeschichte, 2002).

[187] The adoption of Tartaglia's translation to study Euclid (*Euclide Megarense philosopho: solo introduttore delle scientie mathematiche: diligentemente reassettato et alla integrita ridotto per il degno professore di tal scientie Nicolo Tartarea Brisciano*, Venezia 1543) might have important consequences. That edition, indeed, contained mathematical clarifications that other Latin versions of that time did not mention. For example, in a Latin medieval version based on an Arabic Euclid, the Eudoxian theory of proportion set forth in Book Five had been vitiated by a spurious definition put in place of Euclid's. Another Latin version translated from a Greek manuscript by Zamberti in 1505(*Euclidis megarensis philosophii platonii mathematicarum disciplinarum Ianitoriis: habent in hoc volumine quicumque ad mathematicam substantiam aspirant: … Cum expositione Theonis ac mirandus ille liber Datorum cum expositione Pappi mechanici una cum Marini dialectici protheoria.* Ba. Zamber.Vene. Interprete, edibus Ioannis Tacuini, 1505) contained the correct definition; but it did not clarify the difference between the Eudoxian theory and the medieval arithmetical theory of proportion based mainly on Book Seven. See S. Drake, *Galileo at Work, his Scientific Biography*, (Chicago; London: University of Chicago Press 1978), pp. 3-4.

[188] In Definition 5 of Euclid's Book V we read: "Magnitudes are said to be in the same ratio, the first to the second and the third to the fourth when, if any equimultiples whatever be taken of the first and third, and any equimultiples whatever of the second and fourth, the former equimultiples alike exceed, are alike equal to, or alike fall short of, the latter equimultiples respectively taken in corresponding order". See E. Giusti, *Euclides reformatus: la teoria delle proporzioni nella scuola galileiana* (Milano: Bollati Boringhieri, 1993).

[189] The fifth day of Galileo's *Discorsi* was entirely dedicated to new "Definitions of Euclid's proportions".

Ricci presumably also had a central role in introducing Galileo to the study of Archimedes, although, even in this case, it is not clear which texts were chosen by the master. According to Drake, Ricci "undoubtedly" introduced Galileo to Archimedes via a variety of texts published by Tartaglia in 1543.[190] Drake's assumption – although it has been contested – is supported by the fact that Tartaglia's edition included both *On Plane Equilibrium* and *On Bodies in Water*, two texts which certainly stimulated Galileo to write his first works on hydrostatics.[191] *La Bilancetta* (1586), for example, took inspiration from Vitruvius's account of how Archimedes determined the nature of the fraud associated with the manufacture of Hiero's crown. In this short treatise, after expressing scepticism about Vitruvius's tale (the method attributed to the Syracusan mathematician "was altogether false and lacking that precision which is needed in mathematical questions") Galileo presented his own theory based on Archimedes's laws and described a hydrostatic balance capable of determining the precise composition of an alloy of two metals.[192]

Beyond hydrostatics, Galileo's early interest in Archimedes can be traced to another work of that period: the *Theoremata circa centrum gravitas solidorum,*[193] which, as the title suggests, included a number of theorems elaborated between 1585 and 1587 on the centre of gravity of solid figures. This geometrical problem had already attracted many 16th-century Italian scholars like Commandino and Guidobaldo del Monte, who in their contributions had explicitly referred to Archimedes and his

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[190] *Opera Archimedis Syracvsani philosophi et mathematici ingeniosissimi per Nicolaum Tartaleam* (Venice, 1543). In the frontispiece of this edition, Tartaglia claimed to be the translator of the emended text and the restorer of the images therein. However, it is now known that he had profited from the Latin translation made by William of Moerbecke in the thirteenth century.

[191] Drake's hypothesis that Galileo proceeded from Tartaglia's work on Archimedes is questionable. It is acknowledged that Galileo owned and annotated a collection of Archimedean works published in Basel in 1544 (Archimedes, *Opera quae quidem extant omni*), displaying the Greek text together with the Latin translation by by Iacopo da San Cassiano *Cremonensis* (15th century). The Basel edition, however, did not include *On Bodies in water* and when Galileo and Castelli later referred to this work (see the letter from Castelli to Galileo dated 1 April 1607: "et insieme ho cavati gli piedi dalle sette prime proposizioni di Archimede De iis que vehuntur in aqua"), they mentioned the title of the book as published in Commandino's Latin edition (*Archimedis de iis quae vehuntur in aqua libri duo. A Federico Commandino Urbinate in pristinum nitorem restituti, et commentariis illustrate* – Bononiae, 1565) and not in Tartaglia's (*Liber Archimedis de insidentibus aquae*). Moreover, the study of the centre of gravity of the paraboloid of revolution used by Galileo for his analysis was contained in the second volume of *On Bodies in Water*, and this volume was not part of Tartaglia's edition.

[192] See T.B. Settle, "Experimental sense in Galileo's early works and its likely sources", in J. Montesinos y Carlos Solís (eds.), *Largo campo di filosofare: Eurosymposium Galileo 2001* (La Orotava: Fundación Canaria Orotava de historia de la ciencia, 2001), pp. 833-849; A. Mottana, "Galileo's La bilancetta: the first draft and later additions", *Philosophia Scientiae*, Vol. 21, no 1 (2017), pp. 165-179.

[193] The treatise circulated only among a restricted number of distinguished mathematicians; eventually, it was published as appendix of the *Discorsi* in 1638.

work *On the Equilibrium of Planes* – as did Galileo in his treatise. Galileo's reference to Archimedes in his work was not merely celebrative: it represented a sign of continuity between his own work and that of the "divine" and "incomparable" Syracusan mathematician, but it was also evidence of his increasing predilection for stricter connections between mathematical analysis and physical investigation. The Archimedean method, in fact, can be traced throughout the Galilean production.[194]

Although we do not have sufficient evidence to reconstruct the precise details of Galileo's mathematical training by Ricci, it is clear that the master provided his student with an education that integrated a technical mathematical training with a thorough knowledge of classical authors like Euclid and Archimedes. Moreover, it is important to remark that until 1585, although with less and less enthusiasm, Galileo attended the university, where he developed an extensive knowledge of the Aristotelian natural philosophy, of the dominant astronomical theories of the time, and of their underlying mathematical structure.[195] Such a variety of approaches and themes mastered by Galileo during his education certainly shaped the main traits of his polymathic scientific program, which dealt with mathematics, physics, astronomy, optics, military engineering, scientific instrumentation, and technical issues.

The breadth of his interests helped Galileo to come into contact with many of the leading mathematicians of the time, who soon acknowledged Galileo's skills and ability. It is not by chance that at the end of the 1580s Clavius,[196] the mathematician Giuseppe Moletti,[197] and the mathematician,

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[194] See P. Machamer, "Galileo's Machines, His Mathematics, and His Experiments", in P. Machamer (ed.), *The Cambridge Companion to Galileo* (Cambridge: Cambridge University Press, 1998), pp. 53-79; M. Camerota, "Archimede e Galileo", in G. Di Pasquale, C. Parisi Presicce (eds.), *Archimede. Arte e scienza dell'invenzione* (Firenze: Giunti, 2013) pp.; A. Ciocci, "Galileo e le "maravigliose" Spirali di Archimede", *Physis*, Vol. LIV, 2019, pp. 123-144.

[195] Galileo's professors of philosophy at Pisa were Francesco Buonamici, Francesco De' Vieri, and Girolamo Borro; the professor of mathematics was Filippo Fantoni. See M. Camerota, M. O. Helbing, "Galileo and Pisan Aristotelianism: Galileo's De motu antiquiora and the Quaestiones de motu elementorum of the Pisan professors", *Early Science and Medicine*, Vol. 5, no. 4 (2000), pp. 319-365; M. O. Helbing, "Mechanics and natural philosophy in sixteenth century Pisa: Cesalpino and Buonamici, humanist masters in the Faculty of arts", in W. Roy Laird, S. Roux (eds.), *Mechanics and natural philosophy before the scientific revolution* (Dordrecht: Springer, 2008), pp. 185-193.

[196] G. Galilei, *Opere*, ed. A. Favaro (Firenze: Barbera, 1890-1909), X, pp. 22-24, 27-29. Subsequently cited *OG*.

[197] Giuseppe Moletti was Galileo's predecessor at the University of Padua. In a document dated 29th December 1587, in commenting Galileo's *Theoremata circa centrum gravitatis solidorum*, he referred to its author as "a good and experienced geometer". *OG,* I, p. 183.

astronomer and philosopher Guidobaldo del Monte all emerged as Galileo's correspondents.[198] Galileo's written exchanges with del Monte were copious. In the first letter that Guidobaldo sent to Galileo on 16th January 1588, the former already expressed his great admiration for the latter: "I shall consider it a favour to receive whatever you have written on the centre of gravity. In light of the essay that you sent me, it can only be excellent. I know that I will learn a lot, having found in your essay depth and rigour, and a way of going about that is as beautiful as it is brief and concise". At the time, Guidobaldo was twice as old as Galileo, but he found in him an excellent interlocutor to discuss topics on an equal footing. Besides, in his letters Galileo not only exhibited an amazing knowledge of Archimedes' theorems; he also showed that he was able to improve them by developing new "exquisite doctrines".[199]

Becoming a master

The years following his formative education were quite demanding for the young Galileo: neither his proven ability in mathematics nor the recommendation letters of illustrious noble Florentines – Giovanni dei Bardi di Vernio, Giovanni Battista Strozzi, Luigi Alamanni, and Giovanni Battista Ricasoli – seemed to be enough to gain a position inside the academy. It was only in 1589 that, after the resignation of Filippo Fantoni from his position at the University of Pisa, Galileo obtained the desired mathematical chair. In compliance with the University Statutes, mathematics and astronomy were taught together and aimed at providing future physicians with astrologic competence to determine the days that, according to the Galenic doctrine, signalled a crucial point

[198] On the relationship between Galileo and Guidobaldo see M. Frank, P. D. Napolitani, "Il giovane Galileo e Guidobaldo dal Monte: maestro e discepolo?", In *Scienze e rappresentazioni* (Firenze: L.S. Olschki, 2015) pp. 173-219; W. R. Shea, "Guidobaldo del Monte: Galileo's Patron, Mentor and Friend", in A. Becchi, D. Bertoloni Meli, E. Gamba (ed.), *Guidobaldo del Monte, 1545-1607: theory and practice of the mathematical disciplines from Urbino to Europe* (Berlin: Edition Open Access, 2013), pp. 95-104.
[199] Guidobaldo Del Monte to Galileo in *OG*, X, p. 25.

for the illness.[200] The same statutes also suggested the topics to teach, which included Sacrobosco's *De Sphaera Mundi*, Euclid, and Ptolemy.[201]

Galileo's experience at the University of Pisa was not positive: both the poor salary and the stifling intellectual milieu contributed to his increasing discontent, which can be clearly traced in a satiric poem written in 1590 and entitled *Capitolo contro il portar la toga (Against the donning of the gown*). Meanwhile, the death of Giuseppe Moleto, professor of mathematics at Padua, had raised Galileo's hope for a better position, both intellectually and financially. On this occasion, Guidobaldo del Monte offered his help to Galileo;[202] on 21st February 1592 he wrote to the latter:

> I am sorry to hear that you are not treated as you deserve, and even more unhappy that you have little hope of improvement. If you plan to go to Venice this summer, I invite you to come this way. For my part, I will not fail to do what I can to help you. I cannot leave you in this state, and although my means are modest, I will use them all in your service.[203]

Due in no small part to Guidobaldo's intercession, on 7th December 1592 a large crowd attended the inaugural lecture of the new professor of mathematics – Galileo – in Padua. Guidobaldo's influence was mainly ascribable to the help of his cousin Giovanni Battista del Monte, who was the Commanding Officer of the Venetian Infantry and an important figure in the Paduan milieu. Galileo was grateful to Guidobaldo for his crucial help; the latter, however, modestly claimed no role in that favourable outcome and attributed Galileo's success only to the young mathematician's merit and great knowledge.[204]

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[200] M. Biagioli, "The Social Status of Italian Mathematicians, 1450–1600", *History of Science*, Vol: 27: 1, pp. 41-95.
[201] A. Favaro, "Le matematiche nello Studio di Padova dal principio del secolo XIV alla fine del XVI"*, Nuovi saggi della R. Accademia di scienze, lettere ed arti in Padova*, 9, (1880), pp. 1-92; C. Maccagni, "Le scienze nello studio di Padova e nel Veneto"*,* in G. Arnaldi, M. Pastore Stocchi (eds.), *Storia della cultura veneta* (Vicenza: Neri Pozza, 1981)*,* vol. 3, pp. 135-171.
[202] Guidobaldo del Monte was a prominent figure in the social and intellectual milieu of the time. His father, Ranieri, came from a wealthy Urbino family and acquired notoriety as an officer and the author of two books on military architecture. The Duke of Urbino conferred upon him the title of Marchese del Monte. When Ranieri died in 1587, Guidobaldo inherited his father's title and the family estate of Mombaroccio. W. R. Shea, "Guidobaldo del Monte: Galileo's Patron, Mentor and Friend", pp. 95-6.
[203] *OG*, X, p. 47.
[204] On 10th January 1593 Guidobaldo wrote to Galileo: "You say that you are much obliged to me for your post in Padua. I really did nothing and I do not want you to feel under any obligation whatsoever. You got it on your merit and your great knowledge". *OG*, X, p. 54. See M. Frank (ed)., *L'Epistolario Di Guidobaldo Dal Monte, (1545-1607)* (Urbino, Accademia Raffaello 2022), pp. 94-98, p. 285.

The university teaching in Padua did not diverge from Pisa; mathematics was still considered as an instrumental discipline for future physicians' astrological predictions – indeed, the emphasis on mathematics as a support for medicine was even stronger at Padua. The Paduan milieu, however, was very different from other Italian academic environments: the traditional liberality that Padua had maintained even after the Counter-Reformation made the city a lively and dynamic intellectual centre. Besides public teaching, in Padua Galileo was very active in tutoring students privately. Resorting to private education was very common at that time; as Antonio Favaro has shown, in Padua it was not unusual for gentlemen to attend private classes as auditors of famous teachers, and it was considered more prestigious and even more useful than receiving the official diploma.[205] The professors prized this opportunity: private tutoring represented a way to increase their salary substantially. According to Claudio Bellinati, Galileo offered private tuition from 1596 to 1609,[206] and from 1601 he provided his private students with board and lodging at his own home. This is not a marginal biographical note: establishing a familiar and confidential relationship with students was typical for the Pisan mathematician until his last years.

Besides the financial benefit, private teaching offered Galileo a committed audience and more freedom in the choice of topics than was possible in the university. In most cases, his instruction concerned applied mathematics, especially in the military field, and it included an explication of the use of scientific instruments like the geometric and military compass. Indeed, many young noblemen received Galileo's mathematical instruction as a training for their military career. Other topics of teaching concerned mechanics, perspective, and cosmography. According to Viviani's account, the textbooks used in Padua for private teaching were mainly written by Galileo himself.[207] Among these, we can mention the *Mechanics* composed by 1593.[208] Before being published by Luca Danesi in 1649

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[205] A. Favaro, *Galileo Galilei e lo Studio di Padova* (Padova: Antenore,1966), Vol. I, p. 140.
[206] C. Bellinati, "Integrazioni e correzioni alle pubblicazioni di A. Favaro", in *Galileo e la cultura padovana: Convegno di studio promosso dall'Accademia patavina di scienze, lettere ed arti nell'ambito delle celebrazioni galileiane dell'Università di Padova, 13-15 febbraio 1992* (Padova: Cedam,1992) ed. by Giovanni Santinello, pp. 257-265, p. 264.
[207] *OG*, XIX, p. 606.
[208] A. Favaro, *Galileo Galilei e lo Studio di Padova,* pp. 185-209; S. Drake, "Galileo Gleanings: V. The Earliest Version of Galileo's Mechanics", *Osiris*, Vol. 13 (1958), pp. 262-290.

– seven years after Galileo's death – the treatise circulated widely within Galileo's circle as a scribal publication, and a French version was also translated and disseminated by Marin Mersenne. Another work of this genre was the *Treatise on the Sphere, or Cosmography*.[209] The date of its composition is unknown (probably before 1600); like the *Mechanics*, it circulated only as a manuscript until 1656, when it was published posthumously by the priest Urbano d'Aviso. The content and structure of this short astronomical treatise generally followed Sacrobosco's medieval *Tractatus de sphæra*; although Galileo was already an adherent of Copernicanism, the heliocentric view of the world was not mentioned at all. Still, this work represents an important source for studying Galileo's early acquaintance with the astronomy of his time.

As for the audience, some domestic notes – which helped Galileo to control the economy of his house – allow us to find out more about his private students. We learn, for example, that in March 1602 "the Polish Marco", "Lencischi's butler", and "Donec" began to study mechanics; and that in 1603 "Sweinitz and his brother-in-law Gotuitz" attended private lessons on the sphere.[210] Many students were non-Italian – an indication that at the beginning of the 17th century Galileo's name was spreading throughout Europe not only for his brilliance in mathematics but also for his pedagogical skills. As for the Italians, in his *Racconto Istorico* (1654) Vincenzo Viviani mentioned several names including: "Msgr. Nerli, Archbishop of Firenze; Msgr. Piccolomini, Archbishop of Siena; Msgr. Rinuccini, Archbishop of Fermo; Msgr. Giuliano de' Medici, Archbishop of Pisa; Msgr. Marzimedici, Archbishop of Firenze; Msgr. Giovanni Ciampoli, Brevi's Secretary of Papa Urbano Ottavo; Ser Senator Filippo Pandolfini; Ser Senator Andrea Arrighetti; Ser Cav.r Tommaso Rinuccini; Ser Pier Francesco Rinuccini, Residente a Milano; Ser Mario Guiducci; Ser Niccolò Arrighetti; Ser Braccio Manetti; Ser Canonico Niccolò Cini; Ser Conte Piero de' Bardi; Ser Filippo

[209] R. de Andrade Martins, W. T. Cardoso, "Galileo's Trattato della sfera ovvero cosmografia and its sources", in R. Pisano, P. Bussotti (eds.), *Homage to Galileo Galilei, 1564-2014: reading Iuvenilia Galilean works within history and historical epistemology of science*, *Philosophia Scientiae*, Vol. 21, no 1 (2017), pp. 131-147. S. Drake, *Galileo at Work: His scientific biography* (Chicago: Chicago University Press, 1978), p. 19.
[210] A. Favaro, *Galileo Galilei e lo Studio di Padova*, pp. 186-187.

Salviati; Ser Iacopo Soldani; Ser Iacopo Giraldi; Ser Michelangelo Buonarroti; Ser Alessandro Sertini, et altri".[211]

A few lines further on, among Galileo's private students in Padua, Viviani also mentioned illustrious names like Cosimo II de' Medici, who in 1609 became Grand Duke of Tuscany, and Gustavus Adolphus, king of Sweden. Finally, Viviani hinted at five of Galileo's disciples who after their mathematical training with Galileo went on to receive important assignments in Rome, Pisa, and Bologna: D. Benedetto Castelli, in Pisa and Rome; Ser Niccolò Aggiunti, in Pisa; Ser Dino Peri, in Pisa; D. Vincenzio Renieri, in Pisa; Fra Buonaventura Cavalieri, in Bologna. After naming them, Viviani added:

> To these disciples he [sc. Galileo] used to say that they most had to thank God and Nature for having granted them a privilege conceded only to those people of their same profession, which allowed them to judge with certitude the talent and the ability of those men who, involved in geometry, were their listeners; because the blackboard stone on which geometrical figures were drawn was the touchstone of the intellects, and those who failed that test [sc. geometry] could dismiss themselves not only as inept in philosophy but as incompetent in every handling or exercise of civil life.

This passage, written by one of Galileo's most illustrious disciples, delivers three important messages: firstly, only those who had a sufficient degree of talent could understand mathematics; secondly, teaching mathematics helped in sifting the good students from bad ones; thirdly, mathematics was fundamental not only to natural philosophy but to every aspect of civil life.

Viviani's comment on the material culture of mathematical pedagogy evokes two iconographic representations in which the "blackboard stone" is represented as strictly related to the teaching of mathematics.[212] The first painting is the *Doppio Ritratto* by Jacopo de' Barbari, which represents the Franciscan friar Luca Pacioli teaching one of his disciples the 8th Proposition of the XIII book of Euclid's *Elements*.[213] In the painting, Pacioli follows Euclid's text with his left hand

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[211] V. Viviani, *Racconto Istorico*, in *OG*, XIX, p. 628-629. It is interesting to note that many of the students mentioned in Viviani's list went on to become archbishops.
[212] See A. Ciocci introduction to G. Maggini, D. Santori, *Niccolaus Adjunctus burgensis, uno scienziato, discepolo e amico di Galileo* (Edizioni Nuova Phromos, 2020), pp. 13-42.
[213] R. Baldasso, "Portrait of Luca Pacioli and Disciple: A New, Mathematical Look", *The Art Bulletin*, March–June 2010, Vol. 92, No. 1, pp. 83-102; A. Ciocci, "Il doppio ritratto del poliedrico Luca Pacioli", *De Computis - Revista Española de Historia de la Contabilidad*, 8 (15), December 2011, pp. 107-130.

while with his right hand he draws on a blackboard the geometric figure related to the theorem in question – an equilateral triangle inscribed in a circle.



Doppio ritratto (1495) by Jacopo de' Barbari, Museo di Capodimonte (Naples).

The second image is contained in Raffaello's *School of Athens* and represents Euclid – depicted by Raffaello with the face of the painter Donato Bramante – surrounded by a group of students and bent over a blackboard in the act of drawing a hexagram with compasses.



Scuola di Atene (1509-11), Raffaello, Stanza della Segnatura, Musei Vaticani (Rome)

In these two Renaissance paintings, the blackboard represents an essential instrument for supporting the didactic purposes of mathematics. A century and a half later, Viviani was using the metaphor of the blackboard stone to highlight the essential role that mathematics – and its teaching – played in the Galilean program.

Galileo had stressed the centrality of mathematics from the very beginning of his activity; in his juvenile dialogue *De motu*, for example, one of the characters exclaimed:

> "Oh! Subtle invention, most beautiful thought! Let all philosophers
> be silent who think they can philosophize without a knowledge of divine mathematics!"[214]

References like this are distributed throughout Galileo's works. They were not merely a celebrative reminiscence of Plato; strengthening the connection between mathematics and natural philosophy was essential to the foundation of a new Physics and, ultimately, for the establishment of a new world view.[215] Galileo's demand for the title of Mathematician and Philosopher of the Grand Duchy of

[214] *OG*, I, p. 401.
[215] In his essay "Galileo and Plato", Koyré writes: "As a matter of fact the *Dialogue*, as I believe I have shown in my ill-fated volume, is not so much a book on science in our meaning of the term as a book on philosophy – or to be quite correct

Tuscany, besides, was certainly motivated by financial and social reasons, but it was also deeply implicated in the project of defending a *mathematical* natural philosophy.[216] The frontispiece of *Il Saggiatore* (1623) is emblematic in this sense: contrarily to the *School of Athens*, in which Raffaello placed philosophy at the peak of knowledge and the liberal arts (quadrivium) at its base, Galileo placed the allegories of natural philosophy and mathematics at the same level, as to stress even visually the necessity to use mathematical principles in natural philosophy.

Galileo's epistemological proposal was ambitious and challenging; soon, indeed, it aroused overt attacks from the Peripatetics: "mathematical proofs and propositions cannot grasp the true cause of natural phenomena" – stated Vincenzo di Grazia in commenting on Galileo's *Discorso intorno alle cose che stanno in su l'acqua* (1612); "those who want to demonstrate natural accidents through mathematical methods" added an anonymous critic "are delirious".[217] Throughout his entire life, each of Galileo's treatises – *Sidereus nuncius*, *Discorso intorno alle cose che stanno in su l'acqua*, *Istoria e dimostrazioni intorno alle macchie solari, Il Saggiatore*, *Dialogo sopra i due massimi sistemi del mondo* – provoked disputes. In many cases, disagreement was rooted in the contrast between two different views, but Galileo was pushing the idea that a constructive debate could be established only when all sides agreed that the common language of mathematics should be used in natural philosophy:

> Philosophy is written in this grand book – I mean the universe – which stands continually open to our gaze. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering about in a dark labyrinth.[218]

This famous quote from *Il Saggiatore* not only expressed an ontology and an epistemology but also articulated the view that mathematical expertise was a key requirement for being a natural

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and to employ a disused but time-honoured expression, a book on natural philosophy – for the simple reason that the solution of the astronomical problem depends on the constitution of a new Physics; which in turn implies the solution of the philosophical question of the role played by mathematics in the constitution of the science of Nature". A. Koyré, "Galileo and Plato", *Journal of the History of Ideas*, Vol. 4, No. 4 (Oct., 1943), pp. 400-428, p. 419.

[216] M. Biagioli, *Galileo, Courtier: The Practice of Science in the Culture of Absolutism* (Chicago: The University of Chicago Press, 1993).

[217] *OG*, IV, pp. 379-439.

[218] *OG*, VI, p. 232.

philosopher. Galileo's claim that the language in which Nature was inscribed was fundamentally mathematical, and that one therefore needed expertise in mathematics to read it, inevitably recalls Copernicus's use of the expression *mathemata mathematicis scribuntur*. By considering both the intellectual significance of mathematics along with its technical difficulty, the Polish astronomer had affirmed that the capacity to fully grasp the truths of natural philosophy was open only to a few, while those ignorant of the proper language could only flounder blindly in a maze.

It is also notable that – as can be traced in many of Galileo's writings – he and his interlocutors often distinguished between capable and "vulgar" or "ignorant" mathematicians. Already in 1597, in writing to Kepler, he had expressed disdain for "the crowd" – considered as a nuisance for the philosopher's research into the truth.[219] In his last work (*Discorsi*, 1638), Salviati responded to Simplicio that having perfect knowledge of Euclid's *Elements* was a necessary requisite for being a "non-vulgar" mathematician – a quote that advocated the defence of a sort of specialist language.[220] Bonaventura Cavalieri, one of Galileo's most significant disciples, was adamant about the superiority of mathematics – "the only real nourishment of the intellect" – with respect to physics and other disciplines; the fact that great mathematicians were traditionally a small minority and less famous than astrologers that practised average calculations was a sign of distinction.[221]

The consequence of the thesis of *Il Saggiatore* was that natural philosophers had to be masters of the language of mathematics. This requirement, however, did not imply that the non-expert could never grasp the basic elements of Galileo's scientific achievements. After the

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[219] "Like you, I accepted the Copernican position several years ago and I discovered from thence the causes of many natural effects which are doubtless inexplicable by the current theories. I have written up many of my reasons and refutations on the subject, but I have not dared until now to bring them into the open, being warned by the fortunes of Copernicus himself, our master, who procured immortal fame among a few but stepped down among the great crowd (for the foolish are numerous), only to be derided and dishonoured. I would dare publish my thoughts if there were many like you; but, since there are not, I shall forebear". *OG*, X, p.68.

[220] "SIMP. Your demonstration proceeds too rapidly and, it seems to me, you keep on assuming that all of Euclid's theorems are as familiar and available to me as his first axioms, which is far from true. SALV. Indeed, all real [non vulgari] mathematicians assume on the part of the reader perfect familiarity with at least the elements of Euclid". *OG*, VIII, p. 272.

[221] Cavalieri to Torricelli, 14 July 1642, in Paolo Galluzzi & Maurizio Torrini (eds), *Le Opere Dei Discepoli di Galileo Galilei. Volume II: Carteggio 1649–1656* (Florence: Giunti-Barbèra, 1984), pp. 17-18.

publication of *Sidereus Nuncius*, in line with the increasingly public dimension of science, the Pisan mathematician often emphasized his desire for a wider circulation of his treatises and justified the employment of the vernacular to achieve that purpose.[222] Galileo's strategy for disseminating his scientific achievements, indeed, involved two different levels of communication: on the one hand, he established a dialogue with competent mathematicians and natural philosophers to validate his arguments and build consensus among experts; on the other hand, he intended to make scientific knowledge "intelligible by many" and to disseminate it as much as possible throughout a wider readership.

The essential role of disciples appears now more clearly: Galileo needed qualified and trusted allies to develop his pioneering scientific project, defend it from the attacks of those who did not speak the mathematical language, and disseminate it throughout an amorphous readership. Mathematical education and reciprocal trust could both be obtained by the personal instruction of a master as a peculiar process that moulded *disciples* – and not mere pupils or followers. Not all pupils could be talented or trusted; "followers" were generally admirers without the desired proximity to the master. Only disciples fitted the requirements. And only disciples could share the values of the new *mathematical* natural philosophy promoted by Galileo. The new gospel required its proper disciples.

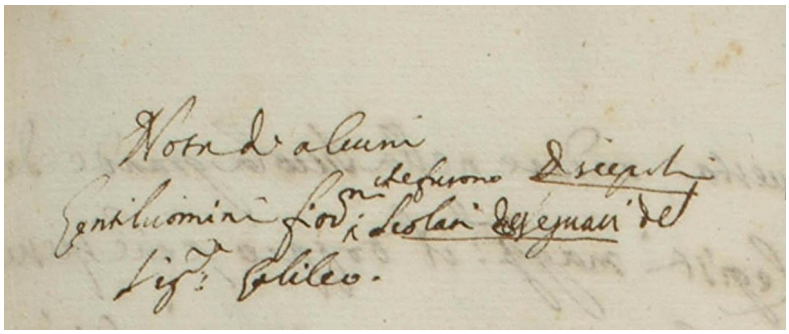
Galileo's first disciple: Benedetto Castelli

Many historians, including Galileo's early biographers, have devoted much attention to the assorted types of intellectuals that surrounded the Pisan mathematician throughout his life.[223] Galileo's wide correspondence, indeed, indicates that many scholars, in Italy and abroad, declared their admiration for his ideas and helped him to spread his work. Among these people, we could mention a huge number of collaborators, pupils, learned friends, and admirers who, at different

[222] See Galileo's letters to Giuliano de' Medici (*OG*, XI, p. 335) and to Paolo Gualdo (*OG*, XI, p. 327).
[223] A. Favaro, *Amici e corrispondenti di Galileo* (Firenze: Salimbeni, 1983). F. J. Baumgartner, "Galileo's French correspondents", *Annals of Science*, Vol. 45, 2, 1988, pp. 169-182.

stages and with different roles, were involved in Galileo's scientific project. But if we restrict our inquiry to those few intellectuals who shared with him thoughts and concerns, and who extended, developed, and disseminated his work – the disciples – the number becomes much smaller.

The proper designation of Galileo's closer associated represents a crucial step to understand the dynamics that animated his scientific enterprise. The importance of such denomination, indeed, concerned even the most famous of his acolytes, Vincenzo Viviani, who while writing Galileo's biography was uncertain about the word to use. In a handwritten note of his *Racconto Istorico* we can discern this uncertainty:[224]



Racconto Istorico's handwritten draft by Vincenzo Viviani, National Central Library of Florence (Ms Gal. 11, folio 64r)

Viviani at first wrote the word "scolari" (pupils); then he opted for "seguaci" (followers); finally, he added – and chose – the word "discepoli" (disciples). Disciples were those most talented pupils who had gained the trust of the master and shared his views, project, and enemies. They were able to defend him and his ideas, had the authority to spread his notions, and were united by that special sort of veneration and affection for the master that marked out the disciple as a "special" pupil.[225] Galileo educated them to see themselves as the few, exceptional mathematicians who were very different

[224] M. Segre, *In the wake of Galileo*, p. 50. Viviani's original document is preserved at the National Central Library of Florence (Ms Gal. 11, folio 64r).
[225] A general account of the main features of the master-disciple relationship is provided by: F. Waquet, *Les enfants de Socrate: filiation intellectuelle et transmission du savoir, XVIIe-XXIe siècle* (Paris: Albin Michel, 2008).

from the crowd and from the "calculators"; and seeing themselves as a restricted circle, very early they began to designate themselves as a "School".[226]

The first scholar to be clearly understood and characterised as Galileo's disciple was Antonio Castelli, known as Benedetto after joining the Benedictine order. Born in Brescia in 1578, he received his mathematical education in his city of birth. After moving to the monastery of S. Giustina in Padua, in 1603, he was attracted by Galileo's reputation and soon was magnetized by his teaching.[227] In three years they established a durable and long-lasting relationship that was largely conducted through a regular and massive correspondence. Since Castelli's instruction at the feet of Galileo happened outside the institutional context, its details are unclear; two excerpts from Castelli's letters, however, help in acknowledging important features of the period of contact between them. The first clue is in a letter dated 1st April 1607 when Castelli, who had been transferred to the Benedictine Abbey of La Trinità della Cava, updated Galileo on the progress of his studies: the reading of Euclid was causing several troubles for the Benedictine, who was "suffocated by the multitude of terms (to confess my sin), the deepness of the things, and the difficulty of the demonstrations". Castelli's readings also included Ptolemy – presumably his *Almagest* – and even in this case the young mathematician was struggling to understand passages such as the first corollary of the twelfth chapter; accordingly, he asked Galileo if he could pick his brain.[228] Castelli also mentioned obscurities in the *Spherical elements* by Theodosius and Archimedes' *De iis que vehuntur in aqua*.[229]

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[226] This expression was first used by Benedetto Castelli on 2nd March 1641, when he wrote a letter to Galileo in order to introduce one of his former students, Evangelista Torricelli, to the master: "you will see how much honour he [Torricelli] will bring to your school". *OG*, XVIII, p. 303. See F. Favino, "In urbe mathematicus: Torricelli a Roma", *Galilaeana*, VI, 2009, pp. 39-70.

[227] Antonio Favaro supposed that Castelli was one of Galileo's private students in Padua – and not a public listener. A. Favaro, *Galileo Galilei e lo Studio di Padova*, p. 192-3.

[228] In this passage, Castelli was presumably referring to Book XII – which he mentioned as a "chapter" – of Ptolemy's *Almagest*. The "first corollary" that Castelli did not understand probably refers to the "preliminary lemma" mentioned by the Greek astronomer at the beginning of the twelfth book: "Now that we have demonstrated the above, the appropriate sequel would be to examine the greatest and least retrogradations associated with each of the 5 planets, and to show that the sizes of these, [as computed] from the above, hypotheses, are in as close agreement as possible with those found from observations." Ptolemy, *Almagest* translated and annotated by G. J. Toomer (London: Duckworth, 1984), p. 555.

[229] *OG*, X, pp. 169-170.

If from this 1607 letter we learn what readings Galileo had suggested to his pupil, a much later letter dated 20th September 1638 reveals something even more informative. In the latter Castelli had written to Ferdinando Cesarini – an Italian poet and physicist, brother of the better-known Virginio Cesarini (1596–1624) to whom Galileo addressed *Il Saggiatore* – to discuss a medical case. At a certain point, the case brought to Castelli's mind an experiment performed by Galileo more than thirty-five years earlier:

> [sc. Galileo] took a small glass flask, about as large as a small hen's egg, with a neck about two spans long and as fine as a wheat straw, and warmed the flask well in his hands, then turned its mouth upside down into a vessel placed underneath, in which there was a little water. When he took away the heat of his hands from the flask, the water at once began to rise in the neck and mounted to more than a span above the level of the water in the vessel. Galileo had then made use of this effect in order to construct an instrument for examining the degrees of heat and cold.[230]

The experiment in question is the one performed by Galileo with the thermoscope, an instrument consisting in a tube in which a liquid rises and falls as the temperature changes. Besides the importance of the experiment itself, what is interesting is that Castelli dated the experiment in 1603, which fits neatly with the period of contact between master and disciple. Galileo had evidently involved his student in observing and possibly performing the experiment, meaning that experimentation was a significant part of the training.

Throughout his life Castelli was an exemplary disciple; the tone of his letters to Galileo was always steeped in reverence, devotion, and loyalty. His talent and brilliance in mathematics contributed both to the development and spread of Galileo's theories. On 5th December 1610, for example, in thanking Galileo for a copy of the *Sidereus Nuncius*, he made an acute suggestion to his master about the observation of Venus, implying consequences that would "convince even the most obstinate minds".[231] A few days later, on 11th December, Galileo announced the discovery of Venus's phases to Giuliano de' Medici through a well-known anagram, and on 30th December he wrote to his disciple:

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[230] *OG*, XVII, p. 377.
[231] *OG*, X pp. 480-482.

> Oh how many consequences and ones of such import have I deduced, my Master Benedetto, from these and from my other observations. You almost made me laugh when you said that with these manifest observations the obstinate could be convinced. Well then, don't you know that to convince those capable of reason and anxious to know the truth the other demonstrations already produced were enough, but to convince the obstinate who care only for the empty applause of the stupid and dull crowd, the testimony of the stars themselves, come down to earth to discuss themselves, would not suffice? Let us then endeavour to learn something for ourselves and rest satisfied with this alone, but as for advancing ourselves in popular opinion or gaining the assent of philosophers in books, let us give up the desire and the hope.[232]

It is unclear whether Castelli's suggestion prompted Galileo to turn his "marvellous glasses" to Venus – maybe he had already done it; but the episode manifests the intellectual intimacy between master and disciple. The two also collaborated on the observations of sunspots: at the beginning of the 1610s, while Galileo was observing the phenomenon, it was Castelli who suggested performing the observations by projecting the sun's image onto a sheet of paper by making use of an early helioscope.

Castelli expressed his many insights in numerous letters to his master,[233] whose esteem for and trust in his brilliant disciple increased considerably. By the end of 1610 Castelli was ready to participate actively in the philosophical debates of that time, though still under Galileo's guidance. The first occasion occurred in 1611, when Galileo was involved in a heated dispute with some Tuscan Aristotelian philosophers on the subject of floating bodies. After several informal discussions, the confrontation assumed a formal tone that prompted him to publish the treatise *Discorso intorno alle cose che stanno in su l'acqua* (1612). There, following the Archimedean theoretical model, Galileo sustained his thesis by deploying advanced mathematical exercises that his Peripatetic interlocutors – philosophers, but not mathematicians – did not understand. Notwithstanding this lack of relevant expertise in mathematics, the Aristotelians promptly responded to Galileo's work.

It was at that moment that Castelli's name began to circulate inside the philosophical milieu; Galileo, indeed, let his disciple publish harsh replies for those opposing him, although most of the

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[232] *OG*, X, pp. 503-504. See A. Favaro, "Galileo Galilei, Benedetto Castelli e la scoperta delle fasi di Venere", *Archivio di Storia della Scienza*, Vol. 1, 1919-1920, pp. 283-296; P. Palmieri, "Galileo and the discovery of the phases of Venus", *Journal for the History of Astronomy*, Vol. 32, pt. 2 (2001), pp. 109-129.

[233] When addressing Galileo in letters, Castelli always used the expression "*P.ron mio*" (my master) and signed himself as "*Devotissimo Ser.e e Discepolo*" (Very devoted servant and disciple). See A. Favaro, *Amici e corrispondenti di Galileo Galilei. XXI, Benedetto Castelli* (Firenze: Salimbeni 1983), pp. 739-870.

texts were written by Galileo himself. In his *Racconto Istorico*, Viviani explained the reason for Galileo's choice: after "the whole Peripatetic crowd arose against such a discourse [sc. *On the floating bodies*]", it was Castelli who replied to them "in order to save his master from dealing with frivolous controversies, full of perverted malignity as well as crass ignorance".[234] In a later version, however, Viviani changed his tale: he reported that the reply published by Castelli was entirely – or at least partially – dictated by the master to his disciple. Pretending that Castelli was the author of the text, in fact, was only a device "not to give excessive honour with his name to such weak rivals".[235]

Whatever the reason for Galileo's choice of involving Castelli in the debate, this episode highlights a strong intellectual association between master and disciple: their combined support for the same scientific cause made their names interchangeable.[236] Besides the discussion on hydrostatics, Castelli – and implicitly Galileo – imputed to his addressees an unwarranted presumption in disputing against a geometer notwithstanding their evident lack of competence in mathematics.[237] As a team, Galileo and Castelli were affirming their mathematical expertise in philosophical questions against those who, untrained in geometry, did not speak that language.

In 1613, upon Galileo's recommendation, Castelli was appointed as professor of mathematics at the University of Pisa. This title invested his voice with authority inside the academic context, although his efforts were still instrumental for advocating Galileo's cause. This was the case on 12th December of that same year when, at a banquet at the Tuscan court, Castelli became embroiled in a discussion about the Copernican system. On that occasion, the disciple articulated Galileo's arguments about reconciling the Copernican theory with certain biblical passages. Two days later, he

[234] *OG*, XIX, p. 613.
[235] V. Viviani, *Quinto Libro degli Elementi d'Euclide ovvero Scienza Universale delle Proporzioni Spiegata colla Dottrina del Galileo* (1674), p.105.
[236] Allowing a disciple to publish something written by the master was very popular practice at the time. Galileo recurred to this expedient also in 1618 when, in response to Orazio Grassi's *De Tribus Cometis Anni MDCXVIII,* he published the *Discourse on Comets* under the name of his pupil Mario Guiducci.
[237] See, for example, Castelli's reply to Giorgio Coresio, in *OG*, VI, p. 247. F. P. De Ceglia, *De natantibus. Una disputa al confine tra filosofia e matematica nella Toscana medicea (1611-1615),* Bari, G. Laterza, 1999, pp. 95-140.

reported the facts to his master who, on 21st December, answered on the subject through the well-known *Letter to Benedetto Castelli*.[238]

The correspondence between Castelli and Galileo during this period reveals that although the disciple had acquired his own independence as a scholar,[239] his attitude toward Galileo was becoming increasingly deferential and devoted.[240] Being a disciple, indeed, meant in some ways managing or balancing distance from and proximity to the maestro. Moreover, the exchange between master and disciple shows that the relationship had acquired an emotional tone. The most common sentiment expressed by Castelli's missives was melancholy. What the disciple bewailed the most was being far from his master and missing his direct teaching of mathematics. After leaving Padua in 1607, Castelli was particularly keen to return and continue his studies with Galileo. When, after the publication of *Sidereus Nuncius,* Galileo moved to Florence as Chief Mathematician of the Tuscan Duchy, Castelli requested a transfer to the Benedictine abbey of Santa Maria di Firenze, where he moved in 1611. The two separated again in 1626 when Castelli became a consultant to the Pope on the management of rivers in the Papal States and professor of mathematics at the University of Rome. From Rome, Castelli made frequent trips to Florence to discuss hydraulics with Galileo, besides corresponding regularly with him on this and other topics. He nonetheless expressed his disappointment at being far from his master. In a letter dated 1627, for example, he wrote: "As for my personal taste I'd prefer to eat small fishes from the Arno [sc. Florence] than sturgeons from the Tiber [sc. Rome]".[241] Castelli's rhetorical sorrow became even stronger when, after the publication of the *Dialogue,* Galileo was condemned to lifelong imprisonment. Now more than ever the disciple attempted to move closer to

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[238] M. Camerota, F. Giudice, S. Ricciardo, *Galileo ritrovato: la lettera a Castelli del 21 dicembre 1613* (Brescia: Morcelliana, 2019).

[239] Besides the professorship, Castelli's independence as a scholar is attested by the publication of several treatises: the most important is *On the Measurement of Running Waters* (1628), a book that many scholars consider as the foundation of modern hydrodynamics. Castelli was also very productive in studies about illumination, vision, after-images, and diaphragms in telescopes. Moreover, he was a pioneer in the study of differential absorption of heat by different colours. See B. Castelli, *Della misura dell'acque correnti; Alcuni opuscoli filosofici* (Brescia, Morcelliana 2018).

[240] In a passage of the letter written by Castelli after the dinner at the Tuscan court, the Benedictine monk wrote to Galileo: "As I was leaving ...[sc. Don Antonio] explicitly uttered these words: 'Write to Galileo about my having become acquainted with you and about what I said in the chambers of Her Highness'. *I answered that I would report to you about this beautiful opportunity I have had to serve you*". *OG*, XI, p. 606 (emphasis added).

[241] Castelli to Galileo, 21 May 1627, *OG*, XIII, p. 359.

Galileo, but in vain: the opposition of the Barberinis obliged Castelli to remain in Rome. Not even this last measure, however, stopped their collaboration. Castelli's research continued to be conducted in the tradition of Galileo's new science.

The "Galilean sect"

The publication of the *Dialogue* represented an important turning point for their relationship. Before 1632, Castelli's support for both Galileo's life and work was of the greatest importance: he was a qualified interlocutor, a concrete support, and a loyal friend. After Galileo came out with the most overtly Copernican of his works, however, Castelli's role became even more significant: now that the gospel was explicitly stated, it was time to spread it. Castelli received the first two copies of the *Dialogue* in May 1632; on 29th May, he had already read it "from the beginning to the end with infinite astonishment and delight. And still," Castelli continued "*I read it again to some, few friends of good taste*, with their wonder, and it always delights me, and it always astonishes me, and I learn from it more and more".[242] Besides his reaction to such a "worthy delivery" of Galileo's "sublime mind", what is important to highlight here is Castelli's gathering of trustworthy acquaintances for a collective reading of the *Dialogue*: in this passage there are the first germs of the "Galilean school". Some months later, on 19th June 1632, in writing again to Galileo, Castelli gave him more information about his companions:

> I often enjoy the discussion with Sr Rafael Masotti [sc. Raffaele Magiotti] from Monte Varchi and Sr Evangelista Torricelli, both very erudite in geometry and astronomy, and *set straight* by me. They come to visit me often, and they read the *Dialogues* with acclaim for the doctrine, the concepts, the language, and the easiness.[243]

Thus, from 1632 Galileo's main apostle, Castelli, began to multiply the channels of dissemination of Galileo's scientific program. His strategy was not to diffuse it among an amorphous crowd – at

[242] *OG*, XIV, p. 357 (emphasis added).
[243] *OG*, XIV, pp. 359-60 (emphasis added).

least, not at this early stage; before wider dissemination, he involved trained and qualified mathematicians to properly master Galileo's doctrine.

The selection, training, and indoctrination – the "setting straight" – of Galileo's disciples was Castelli's responsibility and a sign of the deep trust that Galileo had invested in him. At that time Galileo was very busy and always *en route*;[244] on the contrary, Castelli had an established position in Rome and as professor of mathematics he had the opportunity to meet students and the potential to select the most talented among them. This is what happened with Bonaventura Cavalieri[245] and Niccolò Aggiunti,[246] who were first introduced to mathematics in 1616 by Castelli in Pisa. In a few years, the two students mastered the works of Euclid, Archimedes, Ptolemy, and Apollonius, gaining the esteem of Castelli and, successively, of Galileo himself. Castelli had a central role also in the recruitment of Evangelista Torricelli, who studied mathematics under his supervision in Rome before being introduced to Galileo in 1632. In that same year, while Castelli was absent from Rome, Torricelli kept Galileo constantly informed about the reception of the *Dialogue*. In 1641 he moved to Florence to assist Galileo during his last days, and after Galileo's death, he replaced his master as Court mathematician.[247] Giovanni Alfonso Borelli was another

[244] Since 1610, Galileo made several trips to Rome to take care of the diffusion of his works. He also used to visit friends and discuss with them his scientific ideas. In 1624, for example, he spent two weeks in Acquasparta (Umbria, central Italy) as a guest of the Italian naturalist, and founder of the *Accademia dei Lincei* Federico Cesi. In that occasion, Galileo discussed with Cesi and Francesco Stelluti his empirical approach to demonstrate the movement of the Earth. M. Camerota, *Galileo Galilei e la cultura scientifica nell'età della Controriforma* (Salerno editrice, 2004), pp. 403-405.

[245] For Cavalieri, see E. Giusti, *Bonaventura Cavalieri and the Theory of Indivisibles* (Bologna: Edizioni Cremonese, 1980); S. Levey, "Continuous extension and indivisibles in Galileo", in S. Shapiro, Geoffrey Hellman (eds.), *The History of Continua: Philosophical and Mathematical Perspectives* (Oxford: Oxford university press, 2021), pp. 82-103; K. Andersen, E. Giusti, V. Jullien, "Cavalieri's indivisibles", in V. Jullien, *Seventeenth-century indivisibles revisited* (Cham: Birkhäuser, 2015), pp. 31-55; P. Palmieri, "Superpositions: on Cavalieri's practice of mathematics", *Archive for History of Exact Sciences*, Vol. 63 (2009), p. 471-495; B. Cavalieri, *Lo specchio ustorio* (Firenze: Giunti, 2001). On the relationship between Galileo and Cavalieri see: A. Favaro, *Amici e corrispondenti di Galileo Galilei. XXXI, Bonaventura Cavalieri* (Firenze: Salimbeni, 1983), pp. 1247-1315.

[246] Niccolò Aggiunti put at Galileo's service not only his ability in mathematics but also his extraordinary classical education. On his own initiative, he translated into Latin Galileo's *Discourse on the tides*, an essay written in 1616 as a letter to Alessandro Orsini that attempted to explain the motion of the Earth's tides as a consequence of the Earth's rotation and revolution around the Sun. In 1635 Aggiunti assisted Galileo also in the operations related to the Latin edition of the *Dialogue*. A. Favaro, *Amici e corrispondenti di Galileo Galilei*, XXX, p. 74; G. maggini, D. Santori, *Niccolaus Adjunctus burgensis, uno scienziato, discepolo e amico di Galileo*.

[247] F. Toscano, *L'erede di Galileo. Vita breve e mirabile di Evangelista Torricelli* (Milano: Sironi, 2008).

student of Castelli in Rome. After a few years of apprenticeship, he was introduced to Galileo and was recognized by his mentor as "one of our order" (*nostri ordinis*).[248]

This expression – like many others used by Castelli – evokes a quasi-religious tone. It is worth noticing, indeed, that most of Galileo's disciples came from ecclesiastical contexts: Castelli was a Benedictine monk; Cavalieri belonged to the order of the Gesuati; both Torricelli and Viviani attended a Jesuit school in Rome and Florence respectively. This religious background constitutes an important element to grasp the main features of this kind of relationships – i.e. their internal structure or pecking order. However, it is also useful to understand the institutional basis of the practice and language of intimacy between master and disciples: religious expressions like "to confess my sin" and "sect" are emblematic in this sense. Indeed, the term "disciple" itself reflects such a religious component: after a period of training under the master, a disciple accepted the apostolic mission of evangelization because he believed – in the mathematically demonstrated new system of the world that the master was proposing.

In addition to being prepared to act as a committed and trusted evangelist for the Copernican system, possessing sufficient mathematical talent was necessary in order to become a disciple of Galileo. How was this potential recognised, and in what did it consist of? Firstly, the command of several classical texts – Euclid, Archimedes, Theodosius, Ptolemy, and Apollonius – was an infallible benchmark of someone's mathematical skills. When they introduced themselves to the master for the first time, both Cavalieri and Torricelli mentioned those texts.[249] On 6th March 1619, for example, the former wrote to Galileo: "I've currently studied Apollonius through Serenus's books, and I'll go on, even if with difficulty, to study Ptolemy, of whom I've seen only

[248] *OG*, XVIII, p. 189 and p. 197. Throughout his life, Borelli worked on geometry, physics, astronomy, hydraulics, life sciences, volcanology, and anatomy. He had a leading role inside the Accademia del Cimento. A. Koyré, *The Astronomical Revolution: Copernicus - Kepler – Borelli* (Paris: Hermann; London: Methuen, 1973), translated by R. E. W. Maddison.

[249] Already in 1615, Galileo had mentioned a similar list of classical text in the treatise on the floating bodies written under the name of Benedetto Castelli as a reply to the attacks by Lodovico delle Colombe and Vincenzo di Grazia – *Risposta alle opposizioni del S. Lodovico delle Colombe e del S. Vincenzo di Grazia contro al Trattato del Sig. Galileo de lle cose che stanno in su l'acqua* ["Response to the Disagreements of Ser Lodovico delle Colombe and Ser Vincenzo di Grazia against Signor Galileo's Treatise concerning Objects that Lie on Water"]. *OG*, IV, p. 589.

three books, and I'd need your help to understand it."[250] Similarly, on 11th September 1632, the latter wrote:

> I'm a mathematician, a young one, pupil of the Rev. Father [sc. Castelli] for six years, and for two more years I studied by myself under the Jesuit Fathers. I was the first person who, in the Father Abbot's house, and also in Rome, studied minutely and continuously your book [sc. *Dialogue*] until today, with such a gusto that you can imagine of one who, after having practised well all of the geometry of Apollonius, Archimedes, Theodosius, and after having studied Ptolemy and seen almost everything of Tycho, Kepler, and Longomontanus, finally adhered, compelled by many congruences, to Copernicus, and was of Galilean creed and sect.[251]

Besides, it was Galileo himself who on 21st April 1629, in describing Cavalieri's progress to Cesare Marsili, wrote that the young mathematician had mastered by himself difficult authors like Euclid, Apollonius, Archimedes, Ptolemy and others. "And" – continued Galileo – "moved by the vivacity of his mind, he found a new method of demonstration, with which he demonstrates Archimedes' and other heavy authors' main things much faster".[252]

Having a deep knowledge of the classical mathematical texts was evidently a necessary requirement for becoming Galileo's disciple; however, by itself it was not sufficient to be a member of the Galilean school, which required also a certain "vivacity of mind" to outstep those classical authors and expand their theories. The disciples' willingness to show the capacity to contribute actively – and independently – to the new science is traceable in many of their letters to Galileo. On 15th December 1621 Cavalieri wrote to his master: "I'm demonstrating some of Archimedes' propositions in a different way from the way he did, and in particular the quadrature of the parabola, in a manner that differs from yours".[253] Similarly, twenty years later Torricelli wrote to his master that he had extended Archimedes' doctrines in *De sphaera et cylindro*.[254] Galileo was impressed by the results achieved by those young mathematicians. After reading the script of Torricelli's *De motu gravium*,[255] he did not miss the opportunity to express his admiration for that way "of demonstrating

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[250] *OG*, XII, p. 444.
[251] *OG*, XIV, pp. 387-388.
[252] *OG*, XIV, p. 36.
[253] *OG*, XIII, p. 81. See also *OG*, XIII p. 273.
[254] *OG*, XVIII, p. 332.
[255] Castelli sent the script to Galileo on 2nd March 1641. See *OG,* XVIII, p. 303.

with such ease and gracefulness what Archimedes had explored in his Spirals through hostile and tormented paths". These paths – the Archimedean – seemed to Galileo himself "so abstruse and recondite that, if by studying adventurously one hundred years I would not despair to find other conclusions of this same author, this [sc. conclusion] I would invent neither in one thousand years, nor ever."[256] In many cases the disciples proved to be even more skilled and brilliant than their master.

Once that mathematical expertise was consolidated and trust established, the talented mathematicians were *de facto* disciples. A staunch adherence to Galileo's doctrine represented a privilege[257] but also a responsibility. The disciples were well aware of being part of a very restricted circle – this was evident when Torricelli defined that circle as the "Galilean sect"; and when Cavalieri complained about the fact that he could only engage in serious dialogue with "a pair of men", because "pure mathematics" was "so restricted to be almost incommunicable".[258] Galileo's disciples also knew that they had the great duty to participate in the establishment of a new world-system. They accepted the task with increasing enthusiasm and inspired by Castelli, who shared with Galileo "one same soul",[259] they started their apostolic mission of spreading the word.

The correspondence between Galileo and his various disciples reveals the enthusiastic tone with which they adhered to the master's cause and promised to spread the word. In a letter dated 28th July 1621, for example, Cavalieri proclaimed himself finally "ready" to become Galileo's disciple and to be at his disposal, because this, he told Galileo, would allow him "to manifest your doctrine, which deserves to be preferred to every other, as if [sc. it] was a very natural portrait of nature while the others are like those images that, mirrored in a very agitated water, by appearing in several ways and different pieces, result to the spectators as a very confused drawing".[260] A similar message can be found in other letters by Cavalieri; three months earlier, on 28th April 1621, for

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[256] *OG*, XVIII, p. 358.
[257] See the letter written by Torricelli to Galileo on 29 June 1641 in *OG*, XVIII, p. 334.
[258] *OG*, XIII, p. 323) On 28 July 1621, Cavalieri wrote to Galileo that he could discuss his mathematical theories "with people who have a more than mediocre knowledge"; however, he complained because he could not find with them the desired satisfaction (*OG*, XIII, p. 71). Similarly, on 28 May 1625, he wrote to Galileo: "I have already studied the whole Almagest; but how can this benefit me if for a long period I have not had anyone to talk about it?" (*OG*, XIII, p. 273).
[259] *OG*, XIII, p. 40.
[260] *OG*, XIII, p. 71.

example, he informed Galileo that he did not miss the opportunity to exalt "the rare doctrine and the excellent mind of yours",[261] while in November 1628 he concluded one of his letters by proclaiming his wish that "the fame of your virtue and the light of your rare doctrine always live through my mouth".[262] Such examples can easily be multiplied: in May 1627, Niccolò Aggiunti informed Galileo about his success with some of his students who had apostatised "Peripateticism" in order to undertake "the path of the real and good method of studying" – the Galilean one.[263] In March 1641,Torricelli told Galileo of his "desire to show to my master how, even far from him and in his absence, I had spread his doctrine with some of my studies".[264]

Besides these enthusiastic messages related to Galileo's doctrine, the correspondence of his disciples is also steeped in emotions: a reverential, devoted, and sometimes servile tone frequently alternates with glorious eulogies of Galileo, described as an "Oracle of nature"[265] and a "Phoenix of every mind"[266] by Evangelista Torricelli and Bonaventura Cavalieri respectively. As it had been for Castelli, so the younger disciples manifested their desire for a closer relationship with their master; in analysing such correspondence, sometimes one has the impression of reading love letters. This was the case when Cavalieri wrote: "I can't help but being a major enemy of your infinite occupations, which are the cause of not enjoying even one syllable of answer to my letters";[267] or when Torricelli urged God to quicken the days before his next meeting with Galileo, because he looked forward to enriching himself and collecting "the trifle of those treasures that one can manage in your [sc. Galileo] home, which because of Your presence is the palace of the Truth and the treasury of Wisdom".[268] In his letter of May 1627 Aggiunti went as far as declaring that he was "very much in love" with Galileo.[269]

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[261] *OG*, XIII, p. 61.
[262] *OG*, XIII, p. 456.
[263] *OG*, XIII, p. 357.
[264] *OG*, XVIII, p. 308.
[265] *OG*, XIV, p. 387.
[266] *OG*, XVIII, p. 364.
[267] *OG*, XIII, p. 381.
[268] *OG*, XVIII, p. 327.
[269] OG, XIII, p. 357.

The desire to be closer to the master increased as Galileo became older and almost blind; the need of support and the house arrest made the help of trusted disciples even more crucial. It was in this circumstance that in 1639 Galileo met his "last disciple",[270] the seventeen-year-old Vincenzo Viviani.[271] Soon master and disciple became inseparable; Viviani's constant presence by Galileo's side can be traced in most of the correspondence from 1640 to 1642: at the end of every letter, the senders expressed the warmest greetings not only to the great master but also to his "chancellor" – as Cavalieri defined him in a letter dated 10th May 1640. Far from merely being Galileo's eyes and hands, Viviani was a talented mathematician; the period of close and even intimate contact with the master made him a superb one.[272] As Viviani himself claimed in a passage of his *Racconto istorico*, Galileo's teachings were invaluable:

> Soon after this unexpected publication [sc. *Two New Sciences*], Sig. Galileo allowed me into his villa in Arcetri where he was staying. I was able to benefit from our intelligent conversations and his precious teachings and he was content that in the study of mathematics, which I had only recently begun, I could turn to his own voice for the solution to those doubts and difficulties that I often found through the natural weakness of my intellect.[273]

Galileo's work also benefitted from Viviani's presence. As the master told Castelli in a letter dated 3rd December 1639, the enthusiasm and constant questioning of the young mathematician had led him to further investigation of the geometrical demonstration of accelerating falling bodies, specifically on the notion of ratios between weight and force on inclined planes:

> Objections made to me many months ago by this young man [sc. Viviani] who is now my guest and disciple, against that principle postulated by me in my treatise on accelerated motion [...] made me think

[270] On 4th April 1692, Viviani published a mathematical challenge problem in the *Acta Eruditorum* (*Aenigma geometrico de miro opificio testudinis quadrabilis hemisphaericae*) under the name *D. Pio Lisci pusillo geometra*, which was a fictitious anagram decoded as *Postremo discipulo Galilei* (Last disciple of Galileo). This episode is analysed in detail in C. S. Roero, "Leibniz and the Temple of Viviani: Leibniz's Prompt Reply to the Challenge and the Repercussions in the Field of Mathematics", *Annals of Science*, 47 (1990), pp. 423-43.

[271] The first meeting between Galileo and Viviani was arranged by the Grand Duke of Tuscany Ferdinando II, who had known about Viviani through Famiano Michelini, a court mathematician and mentor of Viviani's teacher Clemente Settimi. See L. Boschiero, *Experiment and Natural Philosophy in Seventeenth-Century Tuscany. The History of the Accademia del Cimento* (Dordrecht: Springer, 2007), p. 37.

[272] R. Raphael's analysis of a copy of the *Discorsi* filled with Viviani's marginalia highlights the importance of studying that work closely with its author. See R. Raphael, *Reading Galileo: scribal technologies and the Two new sciences* (Baltimore: Johns Hopkins University Press, 2017), pp. 47-74.

[273] V. Viviani, *Racconto Istorico* in *OG*, XIX, p. 662.

> about this again in such a way as to persuade him that such a principle might be conceded as true. Finally, to his and my great delight, I succeeded in finding a conclusive demonstration.[274]

After Galileo's death, Viviani continued to extend and strengthen Galileo's research on mechanics and motion: the Fifth Day of the *Two new sciences* – which was accomplished with the help of Torricelli – was published by Viviani in 1674 as *Quinto libro degli Elementi d'Euclide, ovvero Scienza universale delle proporzioni*. In the letter "To the noble students of geometry", to whom the book was addressed, Viviani remembered with nostalgia Galileo's "wise, prudent, and lovely teachings" and celebrated his master as he had already done twenty years before, when in 1654 he had written the first of Galileo's biographies (*Racconto Istorico*).[275] That work, indeed, was only the first of many planned to celebrate the name of his master. Noteworthy, for example, is the decoration of Palazzo dei Cartelloni's facade in Florence, dedicated on the monument by the fond disciple to Galileo and his discoveries. Viviani was also very active in designing a sepulchre to erect in honour of his master, although eventually he did not succeed in overcoming the resistance of ecclesial authorities. Only in 1737 was a funerary monument inaugurated inside the Basilica of Santa Croce. Viviani had died more than thirty years before; his efforts, nevertheless, were not vain, and he still lies there, buried by his master's side.

The world that Galileo proposed to his contemporaries during the 17th century was radically different from the one his Aristotelian professors had taught him at university in the 1580s: the Moon was not a planet but a satellite; there was no distinction between the celestial and the terrestrial worlds; and the Earth was no longer at the centre of the universe but moved around the Sun. Galileo was offering to the intellectuals of the time not only "marvellous lenses" to look at the

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[274] *OG*, XVIII. p. 126. This "conclusive demonstration", which contributed to validating Galileo's proposition that heavy bodies reach equal final speeds when dropped from variously inclined planes, was added by Viviani to the new edition of *Two New Sciences* published in Carlo Manolessi's *Opera Omnia* (1656).

[275] See S. Gattei, *On the life of Galileo: Viviani's Historical account and other early biographies* (Princeton, Princeton University Press, 2019); S. Gattei, "Galileo's legacy: critical edition and translation of the manuscript of Vincenzo Viviani's Grati animi monumenta", *British Journal for the History of Science*, Vol. 50 (2017), pp. 181-228.

sky but also new theoretical instruments to observe phenomena. The metaphor of the Book of Nature as expressed in his *Il Saggiatore,* indeed, constituted a milestone of the Galilean scientific manifesto. The idea of a mathematized natural philosophy shaped not only Galileo's new philosophy but also the new role of the natural philosopher, who was required to master the mathematical language in which the laws of nature are written.

In this context discipleship became an essential means for Galileo to establish a *mathematical* natural philosophy. Throughout his life he struggled against conservative scholars and hostile institutions; he needed allies, but not generic ones. This is the reason why he trained talented students to master mathematics: only expert mathematicians could successfully argue against his enemies and carry on his pioneering scientific programme. Eventually, his investment paid off: his disciples disseminated, developed, and enhanced his ideas. Their strategy consisted in building a strong network operating both inside and outside the academic context: by the 1630s, the most prestigious university positions were occupied by mathematicians of the Galilean school,[276] which were also actively involved inside more informal milieus as intermediaries between the author (Galileo) and his readership. After the publication of the *Dialogue* in 1632 and the consequent condemnation, discipleship became even more decisive. Confined to Arcetri, Galileo was forbidden from corresponding with his scientific interlocutors and his main work was inserted in the list of the prohibited books and confiscated. Only his disciples, as reputed mathematicians in prestigious universities, were able to spread the master's ideas both in Italy and Europe. They continued to exercise an essential role after his death: they bore his intellectual legacy and, despite the ecclesial opposition, they were crucial for the success of his intellectual project and his reputation.[277]

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[276] After twelve years of professorship in Pisa, in 1627 Castelli became lecturer in Rome; two years later, Cavalieri gained the same position in Bologna; in 1639 Borelli was appointed as Professor of Mathematics at Messina; after Castelli, the Pisan chair of mathematics was assigned to Niccolò Aggiunti in 1626, to Dino Peri in 1636, and to Vincenzo Renieri – an Olivetan monk who collaborated with Galileo – in 1640.

[277] L. Boschiero, *Experiment and natural philosophy in seventeenth-century Tuscany: the history of the Accademia del Cimento* (Dordrecht: Springer, 2010).

CHAPTER 4

CULTIVATING A GENIUS.

ISAAC BARROW AND ISAAC NEWTON

The Mathematical Sciences in 17th-century England. Overview of a Pedagogical Reformation

The turbulent events that characterised the English political and religious scene during the seventeenth century had a relevant impact on every institutional sphere in the country, including those in charge of making scientific knowledge. The profound transformations experienced by the Church, the Monarchy, and the English Parliament echoed in the academic context and opened new scenarios that, by the end of the century, would lead to gradual but radical changes. Cambridge and Oxford were the main centres of these transformations; notwithstanding their medieval configuration, which at the beginning of the century was still deeply rooted in their educational systems, they gradually embraced the growing enthusiasm for the rise of the "new philosophy" and the birth of modern science. The flourishing of mathematics and the introduction of new pedagogical practices connected to its study determined a significant increase in the opportunities to study scientific disciplines inside the university. Understanding how the traditional models that characterized the two English universities at the time changed over the century is crucial for examining the promotion of the study of scientific disciplines, which paved the way to the development of the new science. Most of the intellectuals involved in the seventeenth-century scientific movement, indeed, developed and cultivated their interest in the mathematical sciences within the academic walls.

At the beginning of the seventeenth century the life of both the faculty and the student communities was regulated by the Statutes – the Elizabethan Statutes of 1570 at Cambridge and the

Nova Statuta of 1564/65 at Oxford,[278] which also fixed the curricula. During the sixteenth century the Statute of the University of Oxford did not have an authoritative and recognized status – the *Nova Statuta* represented just a compilation of injunctions and articles. It was only during the reign of James I that the first attempts to compile a real Statute were made. When Charles I became king in 1625 and Archbishop Laud was elected as Chancellor of the University in 1630, a coherent version of the statute was finally promulgated. This version, known as "The Laudian Code" of 1634, governed the University for the next 200 years. According to the Cambridge statutes, students were expected to study rhetoric in the first year, logic in the second and third year, and philosophy in the fourth year. The *Nova Statuta* of Oxford, instead, only stipulated that students were expected to attend three terms of arithmetic, two of music, four of rhetoric, two of grammar, and five of dialectics. Although mathematics did not play a central role in undergraduate pedagogy, as a key element in the *quadrivium* it was nonetheless not completely absent from the undergraduates' education.[279]

Before the 17th century the mathematical sciences had always been considered as preparatory or complementary to the study of other subjects. Geometry, for example, was often associated with the study of logic while arithmetic, astronomy, and optics were considered prerequisites for the study of philosophy. It was only during the first half of the 17th century that these disciplines began to appear as autonomous and not simply as a subdivision of the three philosophies:[280] the study of mathematics was gradually integrated into both the BA and the MA curricula and became one of the subjects to be disputed by undergraduates. From 1619 onward, moreover, a sufficient proficiency in mathematics was required to be admitted into colleges at Oxford – a measure that indicates that the revision of the academic curriculum represented only one

[278] See M. Feingold, *The Mathematicians' Apprenticeship. Science, Universities and society in England, 1560-1640* (Cambridge University Press, 1984), p.24.
[279] M. Feingold, *The Mathematicians' Apprenticeship,* pp. 27-28; M. H. Curtis, *Oxford and Cambridge in transition, 1558-1642: an essay on changing relations between the English universities and English society* (Oxford: Clarendon Press, 1959), pp. 83-125.
[280] M. Feingold, "The Mathematical Sciences and New Philosophies", pp. 359-448, 363.

level of a more radical reformation that involved the teaching of mathematical subjects in schools, too. In a few decades, mathematics would acquire the propaedeutic role that dialectics had had for centuries.

One of the main aims of the reformation of the schools consisted in breaking with the Aristotelian tradition; downsizing the importance that logic had always had in the students' education allowed more time to be dedicated to mathematics and other scientific subjects. Still, in the early 17th century, both geometry and arithmetic had a marginal role in grammar schools. The former was routinely included in the students' studies only during the second half of the century; similarly, the latter was integrated some years before the 1650s, though it was still regarded as an "extra subject". Its study, indeed, often required the payment of an extra fee. As for the content of the teaching, in grammar schools students received only an introduction to basic mathematical concepts and they were not allowed to dispute on the subject.[281]

The usefulness of mathematics in shaping minds had been advocated by many intellectuals during both the 16th and early 17th centuries. The Spanish humanist Juan Luis Vives, for example, had praised the mathematical sciences as "particularly suitable for disciplining flighty and restless intellects … for they engage the minds and compel them to action, and do not suffer them to wander".[282] Similarly, both the English headmaster Richard Mulcaster and the lawyer-philosopher Francis Bacon had lauded mathematics for its ability to sharpen the intellects. With a similitude contained in a passage of his *The advancement of human learning* (1623), the latter recommended mathematics as a way of cultivating diligent mental habits: "So that as Tennis is a game of no use in itself, but great use in respect it maketh a quick eye, and a body ready to put itself in all positions, so in the Mathematics the use which is collateral, an intervenient, is no less worthy, than that which is principle and intended".[283]

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[281] F. Watson, *The Beginnings of the Teaching of Modern Subjects in England* (London, 1909), pp. 254-350.
[282] J. L.Vives, *Vives: On Education. A Translation of the De tradendis disciplinis of Juan Luis Vives* (Cambridge, 1913), F. Watson (ed.), p. 202.
[283] M. Feingold, "The Mathematical Sciences and New Philosophies", in Nicholas Tyacke (ed.), *The History of the University of Oxford: Volume IV Seventeenth-Century Oxford* (Oxford University Press, 1997), p. 367.

During the first half of the century, the choice of school textbooks remained strictly anchored to the basic classical education. From the Cambridge statutes we learn that the professor of mathematics was required if teaching cosmography to "interpret Mela, Pliny, Strabo or Plato; if arithmetic, Tonstall or Cardanus; if geometry, Euclid; if astronomy, Ptolemy."[284] Classical authors were assigned in Oxford, too, where the students read Aristotle's physical, astronomical and biological works, Ptolemy, Euclid, Pliny, Theophrastus, Vitruvius, Plato's *Timaeus*, and Seneca. The standard textbooks for the elements of astronomy were Proclus' *Sphaera* and Sacrobosco 's *De Sphaera Mundi*. This continuity with the tradition was even strengthened when, during the first half of the 17th century, a revived form of humanism spread through English academia, affecting not only the choice of textbooks but also the approach to their study. For example, considerable attention was still dedicated to the study of ancient tongues: incoming students were expected to strengthen their proficiency in Latin and Greek, but also in Semitic languages like Hebrew and, to a lesser extent, Arabic. Such a tendency had an evident impact on the professors' activity; being well-versed in Greek was a requirement to be elected as Savilian professor.

The relatively late "institutionalization" of mathematics – the first two chairs of geometry were set in Oxford and Cambridge in 1619 and 1663 respectively -- delayed the acknowledgement of its importance inside the educational system. In this sense, the famous sentiments of one of the most significant and influential 17th-century mathematicians, John Wallis, are representative of the state of this subject during the 1630s, when he entered Emmanuel College in Cambridge: "I did thenceforth prosecute [sc. mathematics] not as a formal Study, but as a pleasing Diversion, at spare hours; as books of Arithmetick, or others Mathematical fel occasionally in my way".[285] A few lines ahead, Wallis explained in more detail the reason for his not-immediate interest in mathematics:

> For I had none to direct me, what books to read, or what to seek, or in what Method to proceed. For Mathematicks, (at that time, with us) were scarce looked upon as Academical Studies, but rather

[284] P. Allen, "Scientific Studies in the English Universities of the Seventeenth Century", *Journal of the History of Ideas*, Vol. 10, No. 2 (Apr., 1949), pp. 219-253.
[285] C. J. Scriba, "The Autobiography of John Wallis, F.R.S.", *Notes and Records of the Royal Society of London*, Vol. 25, No. 1 (Jun., 1970), pp. 17-46, p. 27.

> Mechanical; as the business of Traders, Merchants, Seamen, Carpenters, Surveyors of Lands, or the like; and perhaps some Almanack-makers in London.[286]

The reliability of Wallis's words has been widely discussed by historians;[287] whatever its degree of truthfulness is, however, this statement certainly contributes to acknowledge a certain complexity – and ambiguity – concerning the status of the mathematical teaching inside the academic context in the early 17th-century England.

Besides this aspect, Wallis's words shed light on the need to have a mentor who could "direct" the student and suggest "what books to read, or what to seek, or in what Method to proceed". This remark leads to a consideration of the emergence of a key figure in the educational scenario of early modern England: the tutor. At that time, resorting to private tutors outside university to consolidate education in mathematical subjects was quite common for wealthier students. The rise of colleges as centres of teaching during the sixteenth century, however, opened the way to the rise of this figure inside the university, too. The assignment of the tutor was a coincidental process, and in many cases the core academic interests of the tutor did not fit those of the student who was assigned to him. When this happened, the latter was allowed to benefit from the instruction of a fellow other than his official mentor; the eagerness and the enthusiasm of the students were essential elements to begin a specialized path. The tutor was responsible for the introduction of the rudiments of a certain subject – a grounding that allowed then the pupils to proceed on their own. It was a tutor's task to assign the readings. Introductory manuals – often written by the tutor himself – were usually chosen for the basic instruction; as for the textbooks, the pupil could be assigned more recent and advanced works of astronomy, mathematics, and natural philosophy. When George Fleming entered Oxford in 1689, for example, he was advised by his tutor John Mill "to buy by all means" books along the line of the "new philosophy" like Bacon's *Novum Organum* or Cudworth's *True Intellectual System* (1678).[288]

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[286] C. J. Scriba, "The Autobiography of John Wallis, F.R.S.", p. 27.
[287] M. Feingold, "The Mathematical Sciences and New Philosophies", p. 359-360.
[288] P. Allen, "Scientific Studies in the English Universities of the Seventeenth Century", p. 243.

Besides the educational side, the tutor was also responsible for his student's conduct, religious instruction, and finances. These aspects made the relationship between tutor and student more personal and certainly much closer; in some cases, for example, the student lived for a certain period at his master's place – a practice that was quite common especially outside the university. One of the most emblematic cases of this kind concerns William Oughtred, a minister of the Church of England and a self-taught mathematician, author of the *Clavis Mathematicae* (1631), who gave private tuition in mathematics to many students from Cambridge and Oxford. One of them, Seth Ward, who at the time was a fellow of Sidney Sussex College in Cambridge "came to him and lived with him half a yeare… and learned all his mathematics of him".[289] In the relationship between tutor and pupil, face-to-face teaching was of the greatest importance. Inside the university, instead, the presence of colleges made living with the tutor unnecessary, though there is evidence of cases in which for financial problems the mentor did let his student live with him.

The rise of the tutor represented an important aspect of the general reformation of the educational system in England. The role of this figure promoted a more penetrating instruction inside the academic context and gave the students the opportunity to establish reliable relationships with their mentors. The potential value of this figure in promoting mathematics and natural philosophy, however, was fully accomplished only when the process of reformation was completed with the institutionalization of the mathematical chairs in Oxford and Cambridge. In this new setting, a student interested in the study of the mathematical sciences could receive a proper grounding by the tutor before approaching more complex studies under the supervision of the Professor of mathematics.

The consequences of this change are evident if we look at the topics that John Wallis chose for his lessons as professor of mathematics at Oxford: the introduction of Descartes's analytical geometry and Cavalieri's method of indivisibles together with his own *Arithmetica Infinitorum*

[289] *Ibid.*, p. 229.

signalled that this subject, which had before been “a pleasing diversion”, had now become a “serious study”. On the other hand, the development of mathematics in Cambridge was much slower, as shown by the foundation of the Lucasian chair only in 1663. This step represented nonetheless the beginning of an unprecedented growth that culminated in the achievements of Isaac Newton. Before Newton, however, substantial results were accomplished by the very first Lucasian Professor, Isaac Barrow. His work helped to pave the way for important mathematical discoveries, but his commitment to mathematics was not confined to those developments. Indeed, Barrow’s efforts were mainly addressed to the promotion and advancement of that subject inside the educational context. As the first Lucasian professor, he was instrumental in both institutionalizing the study of mathematics at Cambridge and endorsing its close and necessary connection to natural philosophy.

Isaac Barrow: a bridge between ancient mathematics and the new philosophy

In the context of the development of the teaching of mathematics in 17th-century England, the figure of Barrow deserves a special mention. Scholars often refer to Barrow in relation to the importance that he had as mentor of Isaac Newton, and they examine in what measure the first Lucasian professor instilled a love for mathematics in his promising student. A great deal of scholarly analysis has been devoted to this subject, but there is still room for further research that would highlight all the nuances of their relationship not only concerning the intellectual consequences of their contact but also considering the nature of their interaction. The academic contact between Barrow and Newton represents a significant case study not only because of the obviously exceptional mathematical gifts of the two individuals in question, but because their relationship is also indicative of the emergence of a new kind of master-disciple relationship in the context of the teaching of mathematics in Cambridge.

During the 1660s, Barrow participated actively in the shaping of a new professorship in Cambridge, inaugurating a new institutional figure, a novel pedagogical role for mathematics and,

consequently, a different way of conceiving the master-disciple relationship in the field of mathematics. Newton was part of the first generation of students to experience this new teaching system, and can be seen as the first successful product – both as a brilliant mathematician and as a master – of such a new approach. In 1669, just one year after his MA graduation, he composed his first major mathematical treatise, *De Analysi;* and in that same year he replaced Barrow as the new Lucasian professor. As previous studies have already pointed out, Barrow had a crucial role in Newton's training and education; the analysis of their intellectual affinity reveals how the former shaped the latter in many ways.[290] It is only if we examine their academic relationship from a wider historical and cultural perspective, however, that we can fully account for Newton's early intellectual and pedagogical development. By considering the interaction between master and disciple in relation to the broader changes in the teaching of mathematics at that time in Cambridge, we can identify – and appreciate – the main features of Newton's exceptionality both as a mathematician and as a master.

From this prospective, the figure of Isaac Barrow acquires a different tone: in the wake of Feingold's analysis,[291] one of my purposes is to depict a unified portrait of the first Lucasian professor in which his role as Newton's mentor is considered in strict relation to his commitment to reforming the teaching of mathematics in Cambridge. In order to do so, it is important to look at how Barrow became a master himself, not only to catch the main features of the educational system of his time but also to understand how some of those features were then integrated into the new system. His case, indeed, is emblematic of how some traditional aspects of the role of the tutor were combined with the new institutional figure of the professor; a combination that changed radically both the structure of the academic system and the level of education in the field of the mathematical sciences in Cambridge.

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[290] N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method* (MIT Press, 2009), pp.169-179.
[291] M. Feingold (ed.), *Before Newton: the life and times of Isaac Barrow* (Cambridge University Press, 1990); M. Feingold, "Isaac Barrow and the foundation of the Lucasian professorship", K. C. Knox and Richard Noakes (ed.), *From Newton to Hawking. A History of Cambridge University's Lucasian Professors of Mathematics* (Cambridge University Press, 2003), pp. 45-67.

The analysis of Barrow's education constitutes the starting point for understanding the relevance of the tutor at different levels of a student's instruction. On two occasions, indeed, he established a very close relationship with his mentors. The first one was Martin Holbeach, a religious Puritan and renowned headmaster of Felsted School in Essex. Holbeach was more than a teacher for Barrow: besides the strict discipline and solid grounding in classical learning, he always encouraged his outstanding pupil to further pursue his studies. This was the case, for example, when in a moment of financial difficulty Holbeach took Barrow into his own house, before appointing him "little tutor" to William Fairfax, third Viscount Fairfax of Emley. When he received this assignment, Barrow was only twelve years old, but the commitment of his tutor shows that he had precociously demonstrated that he was both talented and trustworthy.[292]

After the basic education received at Felsted under the guidance of Holbeach, Barrow continued his studies in Cambridge, where he was admitted a pensioner in Trinity College on 25th February 1646 and assigned James Duport as his tutor. Once again, the brilliance of the young student made him worthy of a special relationship with his mentor. When Barrow's family experienced another moment of financial difficulty, Duport – as Holbeach had done before him – renounced all the tuition fees for his pupils and allowed him to live in his room. The Statutes of Trinity College decreed that the tutors had to be considered *in loco parentis* and – Duport added in his "Rules to Fellowcom[moners]" – they had to be consulted by students "for advice and indications, as well as for the resolution of any scruple, or doubt, or difficulty in religion or in learning".[293]

As Barrow's tutor, Duport played a central role in his education: he consolidated his pupil's knowledge in classical studies by reinforcing his learning of Latin and Greek but also by teaching his student eloquence and compositional skills. This focus on such an invigorated form of

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[292] M. Feingold (ed.), *Before Newton: the life and times of Isaac Barrow*, pp. 2-4. M. Craze, *A history of Felsted School, 1564-1947* (Ipswich: Cowell, 1955).
[293] C. D. Preston and P.H. Oswald, "James Duport's Rules for his Tutorial Pupils: A Comparison of two surviving manuscripts", *Transactions of the Cambridge Bibliographical Society*, XIV/4 (2011), pp. 317-362. R. Iliffe, *Priest of Nature*, pp. 56-83.

classicism also meant a tenacious adherence to the Aristotelian philosophy and, in Duport's case, a denigration of the new worldviews of Galileo and Descartes. More generally, in his teaching there was no room for the mathematical sciences and natural philosophy; when the students manifested interest in those subjects, Duport suggested other fellows to whom Barrow might resort. Indeed, this is precisely what happened to Barrow in the late 1640s, when he developed an interest for the natural sciences and began to study mathematics. No evidence survives concerning the nature and content of the mathematical lectures that he attended but it is possible that he heard lessons from John Smith at Queens' College or from Ralph Cudworth at Christ's.

The catalogue of Smith's library - bequeathed to Queens' College upon his death in 1652 – reveals his strong interest in the new science: among other authors there were books by Descartes, Galileo, Oughtred, Archimedes, de Billy, Cavalieri, Mersenne, and Van Schooten. Similarly, a copy of Cudworth's library catalogue confirms his deep interest in the mathematical sciences. Among his books were the works of Briggs, Gellibrand, Harriot, Cavalieri, Torricelli, de Billy, Wallis, and Galileo. The lack of information relating to how Barrow and others received mathematical instruction strengthens the assumption that at that time there was neither a defined path to follow nor an institutional figure to address.[294]

Barrow's interest in mathematics became soon a passion, while his growing enthusiasm for the teaching turned into a vocation. His commitment to general pedagogical reform made of him an enthusiastic promoter of the transformation of mathematical teaching in Cambridge. This was a twofold challenge: on the one hand, mirroring the experience at Oxford, where the Savilian chair had been established in 1619, Barrow promoted the institutionalization of mathematics, acknowledging that in terms of instruction it was essential to fill the gap between the mathematical sciences and the education that the university could offer in other subjects. On the other hand, once the curriculum could offer adequate training in the subject, the students had to be encouraged to

[294] Other possible tutors in mathematics would be the two Trinity College fellows Nathaniel Rowles and Charles Robotham, university lecturers in 1648-9 and 1652-3, respectively.

undertake the study of mathematics; the lack of a proper instruction of that discipline in the previous decades, indeed, had greatly reduced the interest of students in it. During his *Oratio moderatoria in auspiciis termini* – delivered on 30th April 1651– Barrow lamented that at the time only few students chose "to get below the outer surface of divine Geometry and none descend into its solid and profound secrets... two at the most may be engaged in following the clews to the dark and involved labyrinths of Numbers."[295] Descending into the "solid and profound secrets" of mathematics was challenging; unravelling the "labyrinths of Numbers" required a proper guide.

During the first half of the century, the figure of the tutor had been the only possible guide to approach the study of mathematics. In most cases this allowed the students to have at least a basic training.[296] However, this was hardly adequate for producing accomplished mathematicians at a time when the subject was becoming increasingly recondite and arguments were being made about the need to connect mathematics more closely to natural philosophy. It was in this context that in 1663 the Lucasian chair of mathematics was established in Cambridge. The inauguration of this position was quite a late achievement for one of two main universities of England; it was nonetheless the starting point of an extraordinary flourishing in the mathematical sciences, which had its first institutional leader in Barrow. Indeed, powerful evidence of Barrow's pioneering role in promoting mathematical studies within the university can be found in a letter sent to Isaac Newton in November 1687 by the cleric and mathematician Gilbert Clerke, who had been a tutor at Sidney Sussex college in the middle of the century. Clerke recognised that Newton's twin achievements in

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[295] "Nempe dum vos assidue legitis, subtilite dissertis, facunde perorates, quis pudor est utilissimam simul et pulcherrimam Mathesin sua obscuritate quasi obsignatam intra prodigiosos characterum cortices delitescere; *divinam Geometriam paucos ultra superficiem attingere; in solidum, in profundum, in ipsa Scientiae intima, ubi lateant usus magis quam ostentatio, neminem descendere; quod caecos illos et implicates numerorum labyrintos acuminis industrii Ariadneo filo extricare satagant vel duo vel nemo*". I. Barrow, "Oratio moderatoria in auspiciis termini" (1651), in *The Theological Works of Isaac Barrow D.D.* (Cambridge, 1859), vol. IX, pp. 29-30. See M. Feingold (ed.), *Before Newton: the life and times of Isaac Barrow*, p. 21. I. Stewart, "'Fleshy Books': Isaac Barrow and the Oratorical Critique of Cartesian Natural Philosophy", *History of Universities,* vol. 16 (1), pp. 35-102.

[296] The tutor customarily prescribed classical textbooks like Aristotle's physical, astronomical and biological works, Ptolemy, Euclid, Pliny, Theophrastus, Vitruvius, Plato 's *Timaeus*, and Seneca's works. The standard textbooks for the elements of astronomy were Diadochus Proclus' *Sphaera* and John de Sacrobosco 's *De Sphaera Mundi.* P. Allen, "Scientific Studies in the English Universities of the Seventeenth Century", *Journal of the History of Ideas*, Vol. 10, No. 2 (Apr., 1949), pp. 219-253.

embedding high-level mathematics within Cambridge, and in deploying mathematics in his recently published *Principia Mathematica*, owed a great deal to the opportunities for studying the subject afforded by the institution of the Lucasian Chair.[297]

Barrow's attitude in promoting the teaching of mathematics can be also discerned in his first published work of 1655, which consisted of a pedagogical version of Euclid's *Elements*. As explained in the introduction, the text aimed to provide beginners with a simplified and yet accurate version of the Greek treatise – a result that the author certainly achieved by combining his knowledge of ancient mathematics and his enthusiasm for teaching. Barrow's contemporaries welcomed his edition of Euclid's *Elements* with high encomium for its educational value; the textbook, indeed, became an instant bestseller and remained a standard textbook for more than a century. Among other scholars, Sir Jonas Moore and John Aubrey recognized the importance of that pedagogical project: the former admitted that Barrow's text should "be every where follow'd";[298] the latter encouraged his students to "always have Barrow's Euclid in their pockets."[299]

Barrow's *Euclidis elementorum libri XV breviter demonstrati* was only the first of several editorial operations undertaken by the Lucasian professor in his lifetime. In this respect, it is important to mention the publication of his *Lectiones Opticae et Geometricae*[300] in 1669 and his works on Archimedes, Apollonius, and Theodosius, completed by the end of November 1653 and published in 1675. These works attested Barrow's increasing command over some of the more difficult texts of Greek geometry, but also his abilities as a teacher and his belief in the importance of teaching. Barrow's commitment to teaching was emphasized even after his death: his

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[297] Smithsonian Libraries, Burndy Ms. no. 11; I. Newton, *The correspondence of Isaac Newton* (Cambridge, 1958-1977), ed. H. W. Turnbull, J. F. Scott, R. Hall, L. Tilling, Vol 2, p. 493 (later on mentioned as *NC*).
[298] Jonas Moore, *A New Systeme of the Mathematicks* (London, 1681), Preface.
[299] J. E. Stephens (ed.), *Aubrey on Education. A Hitherto Unpublished Manuscript by the Author of Brief Lives* (London and Boston, 1972), p. 109.
[300] Isaac Barrow*, Lectiones XVIII, Cantabrigiae in scholis publicis habitae: in qvibvs OPTICORUM PHAENOMENΩN genuinae rationes investigantur, ac exponuntur. Annexae sunt aliquot lectiones Geometricae*. (London, 1669).

mathematical lectures delivered in 1664, 1665, and 1666 in Cambridge were published posthumously in 1683 under the title *Lectiones Mathematicae.*[301]

The appointment of the professorship of mathematics in Cambridge had significant consequences inside the academic system at different levels. Firstly, the Lucasian professor was formally invested with authority both as a scholar and as a professor. The creation of the professorship, indeed, represented the most significant acknowledgment hitherto of mathematics as a valuable discipline in the educational context. Secondly, the establishment of the professorship gave birth to a new hierarchical order inside the university in the field of mathematics. Both these aspects – the dignification of mathematics as a main subject and the new role of the Lucasian Professor as the official guide in the field of the mathematical sciences – were highlighted by Barrow during his inaugural lecture. In his speech, he did not miss the opportunity to praise mathematics as the discipline worthy of the highest place among other subjects, emphasizing also its crucial role in the study of natural philosophy: "any one not in some Degree conversant in these [sc. Philosophical] Studies will in vain expect to understand, or unlock their hidden Meanings, without the Help of a Mathematical Key". For who can "not be altogether deaf to the Lessons of natural *Philosophy*, while ignorant of *Geometry*?".[302] Barrow's message about the necessity of mastering mathematics in order to disclose the laws of nature – which echoed Galileo's famous passage from *Il Saggiatore* –[303] was stressed even further when, a few passages onwards, the Lucasian professor referred to mathematics by saying: "The Steps are guided by no Lamp more clearly through the dark Mazes of Nature, by no Thread more surely through the intricate Turnings of the Labyrinths of Philosophy".[304]

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[301] Isaac Barrow, *Lectiones matematicae XXIII*; *in quibus Principia Matheseôs generalia exponuntur. Habitae Cantabrigiae A.D. 1664, 1665, 1666* (London, 1683).
[302] I. Barrow, *The usefulness of mathematical learning explained and demonstrated: being mathematical lectures read in the publick schools at the University of Cambridge* (London: Cass, 1970), pp. xxvi- xxvii
[303] "Philosophy is written in this grand book – I mean the universe – which stands continually open to our gaze. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering about in a dark labyrinth". G. Galilei, *Il Saggiatore,* in *OG*, VI p.232.
[304] I. Barrow, *The usefulness of mathematical learning explained and demonstrated,* p. xxxi.

If Barrow's words on mathematics gave evidence of his attachment to the discipline, it was especially clear when – in his inaugural lecture as Lucasian Professor – he talked about his educational role and he expressed the most profound dedication to the subject:

> While I was a private Person not otherwise obliged, being enamoured only with the Loveliness of the Thing, I showed such hearty Desires and Endeavours to have these Sciences in the highest Degree recommended to you; it cannot now be doubted but by Reason of my publick Office, and more solemn Engagement, I will more diligently apply myself to their Promotion according to my slender Ability. But what the Laws do strictly require of me, that I have always shewed the greatest Readiness to perform, so that I did not only willingly admit, but earnestly invited you of my own Accord, to familiar Meetings, so that I not only once or twice every Week opened the Doors of my private Chamber, but daily publish'd the inward Secrets of my Heart, and unfolded my Breast to all Comers. If it be then your Pleasure, ye Lovers of Study, come always... what you may do by your Right, you shall make me do willingly, nay gladly and joyfully. Ask your Questions, make your Enquiries, bid and command.... If you meet with any Obstacles or Difficulties, or are retarded with any Doubts while you are walking in the cumbersome Road of this study of Mathematics, I beg you to impart them, and I shall endeavour to remove every Hindrance.[305]

Barrow's words sound like a proper declaration of love, a solemn oath toward the promotion of the mathematical sciences; his warm encouragement to the students, then, manifested the desire, the enthusiasm, and the commitment to his new magistral role.

Barrow's invitation did not remain unheard, and from his letters to the mathematical intelligencer John Collins[306] it appears that a great number of students attended his lectures.[307] Only one decade earlier, Barrow himself had lamented the paucity of students interested in the study of mathematics; now he was the main promoter of their increasing involvement. From Barrow's correspondence it also transpires that many students sought the new Lucasian Professor in private for further explanations, just as he had exhorted in his oration.[308] This fact highlights how – as we have seen in earlier chapters – the need to create an intimate intellectual master-student relationship was a feature peculiar to the field of mathematics. A certain period of

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[305] *Ibid.*, pp. xxv-vi.
[306] Defined by Barrow as "the English Mersenne", Collins had a prominent role in the dissemination of scientific knowledge during the second half of the XVII century.
[307] S. J. Rigaud (ed.), *Correspondence of scientific men of the seventeenth century: including letters of Barrow, Flamstead, Wallis, and Newton, printed from the originals in the collection of the Right Honourable the Earl of Macclesfield* (Oxford, 1841), vol. 2, pp. 43-46.
[308] *Ibid.*

contact was essential when the teaching involved highly technical arguments, for the master had the opportunity and the ability to intervene immediately and "remove every Hindrance".[309]

The institution of the Lucasian Chair radically changed the teaching system in Cambridge; some elements of the old structure were nonetheless integrated into the new one, giving continuity to the pedagogical tradition. The figure of the tutor, for example, did not disappear; on the contrary every college maintained its own lecturers. The tutor was responsible for providing a basic instruction to his students, a practice that allowed the Lucasian Professor to focus on more specific and advanced topics. This might look like a minor change; actually, it was because of this development that the training of a mathematician in Cambridge changed radically. Within the old system the tutors could only provide a grounding in the mathematical sciences; now, the elementary instruction provided by the tutor became a preparatory training to the mastery of that discipline. When Barrow delivered his lectures, he delved into very technical topics like the relationship between mathematics and natural philosophy and the advanced analysis of the properties of curves. His last series concerned optics and involved the reading of works by Johannes Kepler, René Descartes, and Thomas Hobbes.[310]

Following the creation of the Lucasian chair, growing numbers of students approached the study of mathematics. Their interest was the product of a new educational system that combined different levels of teaching – tutoring and professorship – and which provided the students with a complete set of knowledge in the field of mathematics. Ancient mathematicians like Euclid, Apollonius, and Archimedes were taught together with new philosophers like Kepler, Galileo, and Descartes; the students, moreover, were introduced to the new empirical approach and instructed in the use of the newly developed scientific instruments.[311] This significant change was the product of

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[309] This same feature characterized the Savilian professorship in Oxford: when he founded the chair of mathematics, Sir Henry Savile charged his professors to be "of easy access to the studious who would consult them on mathematical subjects, and particularly to their legitimate hearers". M. Feingold, "Isaac Barrow and the foundation of the Lucasian professorship", K. C. Knox And Richard Noakes (ed.), *From Newton to Hawking,* p. 56.

[310] I. Barrow, *Isaac Barrow's optical lectures, 1667 (Lectiones xviii)* (London: Worshipful Company of Spectacle Makers, 1987), translated by H. C. Fay, edited by A. G. Bennett and D. F. Edgar.

[311] At Oxford Henry Savile invited "the professor of Astronomy, in imitation of Ptolemy and Copernicus, and following in their track, to take astronomical observations as well by night as by day, (making choice of proper instruments

a long process that, during the 1660s culminated in the figure of Isaac Barrow. His passion for the mathematical sciences combined with his pedagogical commitment was instrumental to the development of a new system of teaching and, ultimately, to the shaping of skilled and qualified mathematicians. Among those mathematicians the name of Isaac Newton figures most prominently.

A complex relationship

The relationship between Barrow and Newton represents one of the most interesting case studies in the history of master-student relations in England. Both the fragmentary nature of the documents and the peculiarity of their intercourse made the analysis of this relationship complex and, for certain aspects, impenetrable. In the last decades, several scholars have studied the connection between these two mathematicians, highlighting many important features related to their intellectual bond but also to their actual interaction. Barrow has been widely recognized as the prominent figure in Newton's university education, but it is of course understood that this does not diminish Newton's undoubted capacity for path-breaking independent study. Building on these studies, the purpose of this analysis consists in profiling the main traits of the complex relationship between Barrow and Newton in order to understand the importance of their intercourse for the development of Newton both as a mathematician and as a master.

When they first met in 1664, both Barrow and Newton were at the beginning of a new stage of their careers. In March of that year, Barrow began to deliver lectures as the Lucasian professor while Newton was about to pursue in-depth mathematical studies at Trinity College. It was in the context of obtaining a minor fellowship to continue his studies after his BA that Benjamin Pulleyn, Newton's tutor, arranged for his pupil to have an interview with Isaac Barrow. Newton's strong interest in the mathematical sciences was already manifest and no one in Cambridge was more

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prepared for the purpose, and fitting times and seasons,) and after reducing them to writing, (or at least those in which he has the greatest confidence) to leave them in the archives…[sc. of the University]." A few years later, the Cambridge Statutes specified that a fund was reserved for the purchase of mathematical books or instruments. P. Allen, "Scientific Studies in the English Universities of the Seventeenth Century", p. 226.

competent than Barrow – both for his new position and for his consolidated reputation – to examine such a budding talent. The fact that Newton's tutor resorted to the new professor of mathematics to examine his student's skills highlights how the new Lucasian professorship promoted the creation of a specialized path in the mathematical sciences; just one year earlier the students had no official figure to resort to in order to advance this subject.

John Conduitt – the husband of Newton's half-nice Catherine Barton – reports the anecdote of the initial encounter between Barrow and Newton. This account, whose source was Newton himself, has Barrow examining the student on Euclid, a fact which shows how the Greek mathematician still constituted the main source to test someone's competence in mathematics. On that occasion Newton famously proved to be unprepared, but Conduitt (and one assumes Newton) did not miss the opportunity to highlight Newton's already advanced position in the study of mathematics. Although he was allegedly too shy to admit it to Barrow, Newton was in fact well versed in Descartes's *Géométrie* (which he had encountered through Schooten's 1659-1661 edition), whose study would be difficult to manage without a previous knowledge of Euclid. Notwithstanding Newton's apparent failure in answering Barrow's questions, the examination presumably went well for Newton: he obtained the scholarship. Barrow must have recognized in Newton a promising student to mould into a prominent mathematician. That meeting, indeed, constituted the beginning of a fruitful relationship.[312]

A crucial point of this analysis consists in the definition of the role that Barrow had in Newton's formation. Firstly, we can refer to Barrow as Newton's mentor – intended as a guide and an advisor.[313] This was true during the first years of contact between them, from 1664 to 1669, a period in which Newton was a student at Trinity and Barrow delivered his mathematical and optical lectures. Considering Newton's undivided interest in the mathematical sciences at the time and

[312] Keynes, MS 130.10, f. 2v. See R. Westfall, *Never at Rest. A Biography of Isaac Newton* (Cambridge, 1980), p.102. R. Iliffe, *Priest of Nature*, pp. 86-87.
[313] The word mentor was originally used to indicate a trusted adviser, a guide. *Mentōr* was in fact the name of the adviser of the young Telemachus in Homer's *Odyssey*.

Barrow's leading position in that area of study, there is no doubt that Newton was among the audience of the new Lucasian professor's lectures.[314]Attending these lectures represented an invaluable occasion for Newton. It is likely that, at that early stage of his studies, he benefitted from his mentor's support to strengthen his already structured background in mathematics and to overcome occasional obstacles. Barrow's fondness for the pedagogical aspect of his role had always been manifest and, as he stated in his inaugural speech, he was enthusiastic about providing guidance to his students. Moreover, besides the basic mathematical techniques and concepts, Newton must have been inspired by Barrow's commitment to introducing his students to the most pressing mathematical topics and problems of the time, like the drawing of tangents.[315] The Lucasian professor was a leading scholar among his contemporaries; exposing his students to key mathematical developments was an essential component of his activity.[316]

During the first half of the 17th century, many mathematicians throughout Europe were seeking a solution to several problems related to the world of analytic geometry; the drawing of tangents and the squaring of curvilinear surfaces were among the most discussed of those problems. We cannot establish with certainty whether Barrow introduced Newton to those topics – the young mathematician probably had already read about them;[317] but it is likely that, as a mentor, Barrow had a relevant role in increasing the interest of his promising student toward the development of new procedures. Newton was at the beginning of his mathematical education, and it was just in those years that he gradually developed his own mathematical style and method. Of course, these features resulted mainly from Newton's originality; but it is nonetheless undeniable that Barrow had a significant impact on his pupil's intellectual development. The opportunity presented to Newton

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[314] Several elements of Newton's work support this hypothesis: Newton's demonstration of the inverse relation between area-problems and tangent-problems, for example, is very similar to Barrow's Proposition 11 from Lecture 10; a close resemblance can be found between Newton's fundamental theorem and Barrow's Proposition 19 from Lecture 11. Moreover, Newton's synthetic constructions and demonstrations from first principles are Barrovian in character; they resemble the theorems on quadrature found in Barrow's *Lectiones Geometricae*. See N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method* (MIT Press, 2009), pp. 169-212; R. Westfall, *Never at* Rest, p.99.
[315] See, for example, the topics introduced by Barrow in his Lectures 10 and 11.
[316] Concerning Barrow's original contributions cf. M. Feingold, *Before Newton. The life and time of Isaac Barr*ow.
[317] I. Newton, *The Mathematical Papers of Isaac Newton: Vol. 1 1664-1666* (New York, Cambridge UP, 1967; repr. Cambridge UP, 2008), ed. D.T. Whiteside, pp. 145-154.

to learn about the most significant topics in contemporary mathematics was not confined to the discussing of those issues with a leading scholar in his own college; the richness of Barrow's library, indeed, represented another important factor in the education of young mathematicians. Newton was one of the students who probably benefitted from this advantage: in one of his notes, he stated that he had "borrowed Wallis's works", and it is likely that the copies in question were recommended and lent by Barrow, who owned those books.[318]

The impact of Newton's early interaction with Barrow can be traced in many aspects of his activity as a mathematician. His style displays many similarities to Barrow's. In his early productions, Newton often resorted to a didactic approach; in his treatise *De Methodis*, for example, the mathematical procedures are often explained via explanatory examples and demonstrations. This pedagogical approach is also disclosed at the beginning of the tract when Newton explicitly addressed himself to the *discentes* – a feature that is also characteristic of Barrow's mathematical treatises. Newton's language also displays features that were drawn from his mentor; this is evident when Newton dealt with themes like absolute space and time or the generation of magnitudes in motion.[319] It was Newton himself who in a letter to Hans Sloane in February 1711/12 stated:

> In the generation of lines & figures by motion, Fermat, Barrow & Gregory considered the small particles by w^{ch} the quantities increased in every moment of time & thereby drew tangents. *Dr Barrow called those particles moments & from him I had the language of momenta & incrementa momentanea & this language I have always used and still use*.[320]

The use of this specific language highlights how important Barrow was during Newton's formative years. Looking at a broader picture, his presence was even more decisive: Barrow,

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[318] King's College Cambridge, Keynes, MS 130.12, f. 1r. See M. Feingold, "Isaac Barrow's Library", in M. Feingold (ed.), *Before Newton. The life and time of Isaac Barr*ow, pp. 333-372.

[319] *Ibid.*, p. 170-171. Barrow was an important source for Newton's writings about the relation between God and space. In his tenth Lucasian lecture of early 1665, which Newton attended, Barrow discussed those topics. A few decades later, in the context of his dispute with Leibniz, Newton recalled those lectures. See R. Iliffe, *Priest of Nature*, pp. 92-93. See also R. T. W. Arthur, "Newton's Fluxions and Equably Flowing Time", *Studies in History and Philosophy of Science*, 26, 1995, pp. 323–51.

[320] Additional manuscript in the Cambridge University Library (later on mentioned as CUL Add. MS), 3965(8), fol. 77v. in *NC*, vol 5, pp. XXV, 213; M. Feingold, "Newton, Leibniz, and Barrow Too: An Attempt at a Reinterpretation", *Isis*, Vol. 84, No. 2 (Jun. 1993), pp. 310-338 (emphasis added).

indeed, not only shaped Newton's technical language, but he also moulded the main features of Newton's conception of the language of mathematics.

When he first approached the study of this discipline in late 1664, Newton immersed himself in a large body of mathematical literature that included works of the Savillian professor of mathematics in Oxford, John Wallis.[321] In those texts, Newton could find the roots of the modern analysis that he himself would develop and extend in the following years. These analytical techniques were based on an algebraic conception of mathematics, which favoured the methods of discovery instead of proofs and emphasized the heuristic aspects of the mathematical procedures. The use of numerical patterns and the employment a new symbolism represented essential components of the analytical approach. At this early stage, Barrow presumably supported his student in the navigation of that mainstream; besides, he demonstrated his familiarity with analytical techniques related to tangents when in his Lecture X he proposed a method of finding tangents that resembled Fermat's. On the other hand, however, in the course of his lectures – and probably in private meetings – Barrow introduced his student to the possibility of exploring different avenues of enquiry.[322]

Probably influenced by the classical education received by his tutor James Duport, Barrow believed in a geometrical mode of thought inherited by the Greeks. Magnitudes alone were to be considered as the object of mathematics, which meant that all mathematics could be subsumed under geometry. As he put it, "I affirmed the Whole of Mathematics to be in some sort contained and circumscribed within the Bounds of Geometry. And indeed concerning the other Sciences then mentioned, I imagine no Body will much deny, but they are conveniently enough

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[321] In a note dated 4th July 1669, Newton listed his readings: "I find that in y^{e} year 1664 a little before Christmas I being then senior Sophister, I bought Schooten's Miscellanies & Cartes's Geometry (having read this Geometry and & Oughtred's Clavis above half a year before) and borrowed Wallis's works and by consequence made these Annotations out of Schooten & Wallis in winter between the years 1664 & 1665". CUL Add. MS 4000, fol. 14.

[322] J. Dhombres, "The analysis of the synthesis of the analysis. . . Two moments of a chiasmus: Viete and Fourier", in M. Otte and M. Panza (eds.), *Analysis and Synthesis in Mathematics: History and Philosophy.* Boston Studies in the Philosophy of Science (Dordrecht, Boston, London, 1997), Vol. 196, chapter 7.

reduced to Geometry".[323] Contrary to Wallis, Barrow valued rigour in mathematics and sought synthetic proofs of demonstration without any use of algebraic symbolism.[324] His lectures, indeed, dealt mainly with the geometrical characteristics of curved lines "without the trouble of calculation" – as he stated in his Lecture VI.[325]

Moreover, what characterized Barrow's approach – and what distinguished it from the ancient tradition – was a kinematic approach to geometry. Barrow not only assumed the potential infinity of the possible divisions of a given finite magnitude; he also considered every geometrical magnitude as generated by motion: the continuous motion of a point generates a line, the motion of a line generates a surface, and the motion of a surface generates a solid. Newton gradually embraced his mentor's approach;[326] his growing interest in a geometrical and kinematic conception of mathematics led him to move away from the mathematical world of the moderns in favour of a view that was rooted in the world of the ancients. In 1714, in reference to the controversy with Leibniz, he wrote: "its probable that Dr Barrows Lectures might put me upon considering the generation of figures by motion, tho I not now remember it".[327] Barrow's impact in this sense can be also traced in the justification of the occasional use of the analytical approach, in particular in the employment of infinitesimal magnitudes "for the sake of brevity". This metamorphosis began with the translation of the mathematical language from algebraic to geometrical and in the 1670s resulted in the development of a synthetic method.

As it was for Barrow, in Newton's view the algebraic language provided a proper heuristic tool to solve problems like the drawing of a tangent and the squaring of a curvilinear surface; but it was only with the geometrical language – and with a kinematic view of the

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[323] I. Barrow, *The Usefulness of Mathematical Learning explained and demonstrated* [. . .] (London, 1734), translated by the Revd. Mr. J. Kirkby, pp. 29-31 (Lecture III).
[324] K. Hill, "John Wallis and Isaac Barrow: tradition and innovation and the state of mathematics", *Endeavour*, 1998, Vol. 22 (3), pp. 117-120.
[325] I. Barrow, *Geometrical lectures* (London, 1734). Trans. Edward Stone, p. 100 (Lecture VI).
[326] Newton's kinematic way to determine tangents to mechanical lines, which was devised by the young mathematician in 1665, has many points of similarities with Barrow's way. Add. MS 4000, ff. 152r-163v. See I. Newton, *The Mathematical Papers of Isaac Newton: Vol. 1 1664-1666,* pp. 343-348.
[327] Add. MS 3968.41, f. 86v.

generation of magnitudes – that those problems could be properly demonstrated. The intrinsic mathematical nature of geometric objects and their relations, which constituted one of the crucial elements on which Newton's theory of fluxions was founded, represented a key element in Newton's view. In considering a pair of segments supposed to be generated in equal time by a moving point, for example, Newton not only supposed each segment as generated through motion; he also considered the "speed" of their motion as essential in the study of their relations.[328]

Newton's mathematical intuitions did not remain just ideas; already in the 1660s, while he was still a student at Trinity, the young mathematician began to produce relevant papers in which he illustrated the main results of his studies. When this occurred, an important aspect of Barrow's role as a mentor probably consisted in commenting on his pupil's early research. On the one hand, this was an important element to strengthen the relationship. Each of them was aware of the ingenuity of the other; they both knew that they were discussing highly technical mathematical topics with a valid interlocutor. On the other hand, the intellectual exchange signalled the beginning of Newton's maturity as a scholar, a fact that, to a certain extent, brought to light divergences between mentor and pupil. There is no evidence of Barrow's direct intervention on Newton's papers but the fact that Newton composed his mathematical works while in Cambridge corroborates the possibility of a close interaction between them.

The Master as Patron

Newton's early production – *De Analysi* and *De Methodis* – was a clear sign that the period of training was successfully accomplished. His talent was the main ingredient of the exceptional results that he obtained in a few years; but it is undeniable that the close contact with Barrow contributed to the making of such an outstanding mathematician. This statement acquires even more

[328] M. Panza, "Isaac Barrow and the Bounds of Geometry", in P. Radelat-de Grave and C. Brichard (eds.), *Liber amicorum Jean Dhombre*s (Brepols, 2008), pp. 365-441.

significance if considered in the light of the next stage of the relationship, when Barrow acted to his brilliant pupil as an "academic patron". Once Newton had completed his technical training, it was time to introduce him to the academic world, not as student but as an accomplished scholar. The recognition of this status was underlined by Barrow himself, who in the preface of his *Optical Lectures* addressed Newton as a "*collega noster*" (our colleague).[329] After 1669, Barrow was particularly active in introducing his former student to the most relevant institutions of the time. If in 1664 he promoted Newton's fellowship to Trinity College only for the recognition of a promising talent, now he was certain about the extraordinary potential of a scholar whose rise he had personally supported. In social contexts, the activity of patronage was associated with a process of exchange: the patron received from his *protégé* a certain service in exchange of a better social position usually connected to a remunerative reward. The "academic patron", instead, did not receive any concrete advantage from recommending a student. In the case of Barrow and Newton, the patron ensured that his *protégé* was the next incumbent of the Lucasian Chair.

Barrow's promotion of his student was expressed in two ways. On the one hand he supported Newton inside the college. This is the reason why Barrow, about to become Master of Trinity, resigned from his position and successfully supported the election of his protégé to the Lucasian Chair. Newton was appointed Lucasian professor on 29th October 1669 and, as a tribute to his master, elected to begin his teaching activity with the *Lectures on Optics*, the last subject treated by his predecessor. On the other hand, Barrow aimed at promoting Newton's visibility by introducing him as a promising scholar to the English scientific community. In 1671 he brought Newton's reflecting telescope to the attention of King Charles II, and it was Barrow who later made the actual presentation of the instrument at the Royal Society, an event that secured Newton's fellowship at the prestigious institution.[330] The credibility of a leading scholar like Barrow was a

[329] I. Barrow, "Lectiones XVIII, Cantabrigiae in scholis publicis habitae: in qvibvs opticorum phaenomenorum genuinae rationes investigantur, ac exponuntur" (London, 1669), in W. Whewell (ed.), *The Mathematical Works of Isaac Barrow* (Cambridge,1860), Vol. 2, p.6.
[330] See M. Feingold, "Newton, Leibniz, and Barrow Too: An Attempt at a Reinterpretation", p. 320.

decisive factor in the establishment of Newton's position; his role in Newton's life, however, was not yet done. Once Newton's name was beginning to circulate among the most prominent mathematicians and philosophers, Barrow worked hard to make his works known and appreciated by the scientific community.

At this stage, in the early 1670s, Barrow effectively acted as Newton's agent. With the help of John Collins, he zealously involved his former student in several projects to promote and disseminate his research. Barrow's strategy was twofold: on the one hand, he encouraged Newton to circulate the mathematical results that he had obtained during the years of study in Cambridge via correspondence or publication. In this sense, Barrow's involvement in the production and circulation of works like *De Analysi* and *De Methodis* is emblematic. It was Barrow who sent a copy of the former to Collins in 1669, with the hope of having it printed as appendix of his *Lectiones geometricae*.[331] As for the latter, in a missive dated 20th July 1671 Newton himself wrote to Collins that "partly upon Dr Barrows instigation, I began to new methodiz y^{e} discourse of infinite series".[332] This testimony is highly significant not only as evidence of their interaction, but also of Barrow's role in formulating and directing Newton's research.

Besides the attempt to circulate Newton's own mathematical works, between 1669 and 1676 Barrow and Collins were very persuasive in involving the new Lucasian professor in new projects like the English translation of Kinckhuysen's *Algebra*, the edition of an English version of Bernard Varenius's *Geography*, and a new edition of Barrow's *Euclid* and *Archimedes*. The participation in these projects was probably aimed at increasing Newton's reputation and thus, to a certain extent, at justifying Barrow's choice of a young and unknown mathematician as his successor in Cambridge. Most of those editorial projects, however, were not completed by Newton at that time; the reluctance to publish and to disseminate his mathematical results among an amorphous readership

[331] In a letter to James Gregory dated 20 February 1670, Collins wrote "I believe Mr Newton will give way to have it printed with Mr Barrows Lectures". *NC*, vol. 1, p. 26.
[332] *NC*, vol. 1, p. 68.

was already manifest, and Newton favoured the circulation of his works through private correspondence and scribal publication.

The Disciple as Master

The bond between Barrow and Newton progressively weakened. By 1672 Newton was ready to continue his research on his own and had no need of an intellectual guide. The beginning of the priority dispute against Leibniz, showed that Barrow's contribution to his own intellectual development had been largely erased from Newton's memory, though Barrow still constituted a precious source for strengthening Newton's position in the dispute.[333] Firstly, Barrow represented an indirect witness of Newton's early work on the method of fluxions. This is the reason Newton often mentioned his former mentor when talking about his mathematical results, although he always highlighted the fact that Barrow published his results and read his lectures on the topic only after the acknowledgment of Newton's achievements. In the *Commercium Epistolicum* – a collection of correspondence relevant to the priority dispute between Newton and Leibniz that was distributed to interested parties in the first few weeks of 1713, Newton interpreted the facts to his own advantage:

> So then by the testimony of D^{r} Barrow grounded upon papers w^{ch} I had communicated to him from time to time I had the method here described some years before the Doctor sent my Analysis to M^{r} Collins, that is, some years before July 1669. And this is sufficient to justify what I said in the Introduction to the Book of Quadratures, viz^{t} that I found the Method gradually in the years 1665 & 1666. *D^{r} Barrow then read his Lectures about motion, & that might put me upon taking these things into consideration*.[334]

Underlying the importance of Barrow's role in the context of the discovery of the calculus had an important advantage for the English mathematician, who could use his extensive knowledge of

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[333] A. R. Hall, *Philosophers at war: the quarrel between Newton and Leibniz* (Cambridge, 1980).

[334] Add. MS 3968 f. 166r (emphasis added). A similar indication is given in MS 3968 f. 87r: "The time when these things were invented is confirmed by what M^{r} Collins wrote upon the credit of D^{r} Barrow in his Letters to M^{r} Strode & M^{r} Townley, in these words. In September 1668 M^{r} Mercator published his *Logarithmotechnia* containing a specimen of this method in one only Figure, to wit in the Quadrature of the Hyperbola. Not long after the Book came out I sent one of them to D^{r} Wallis at Oxford, who forthwith gave his sense of it in the *Philosophical Transactions*. Another of them I sent to D^{r} Barrow at Cambridge [viz^{t} in June following] who forthwith sent me up some papers of M^{r} Newton . . . by which & former communications made thereof from the Author to the Doctor it appears that the said method was invented some years before by the said M^{r} Newton & generally applied…". See also Newton's letter to Collins, 10 December 1672 in *NC*, vol. 1, pp. 247-248; Newton to Hans Sloane, ca. February 1712, *NC*, Vol. 5, p. 213.

Barrow's mathematical work to attack Leibniz and to downgrade the originality of his contribution.[335] This weapon, nevertheless, represented a double-edge sword: Leibniz could easily reverse the accusation of plagiarism from Barrow; and in fact he occasionally made the obvious point that the person who was most likely to have benefitted from Barrow was his greatest disciple.[336]

The weakening of the relationship between Barrow and Newton signalled a crucial evolution of their master-disciple bond; since then, each of them mostly proceeded on his own with very few occasional interactions: the former devoted himself to his theological studies; the latter began his intellectual and scientific rise. The intercourse that they had in Cambridge was nonetheless of the greatest importance for both of them. Barrow was a competent mentor, an efficient patron, and a solicitous agent. Newton, on the other hand, proved to be a brilliant student, the student that Barrow, devoted to his pedagogical commitment, had probably always wished to teach.

In the light of the main features of their relationship, a final question might now be posed: could Barrow be defined as Newton's master – thus, could their relationship be identified as a master-disciple relationship? Answering this question requires a preliminary consideration of the word "master" on two different levels. Firstly, regarded in its most general acceptation, the term indicates an acknowledged expert in the field, someone who mastered a certain subject – a proper "Master of Art". In this sense, Barrow is considered in relation to the role that he had as the first Lucasian Professor; his presence in Cambridge opened up the possibility of having a point of reference in the educational process, a proper guide to explore advanced mathematical topics and to get a certain degree of expertise in the field of the mathematical sciences. This was a significant achievement in the English academic context and Barrow was a crucial part of its realization.

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[335] CUL Add. Ms. 3968, f. 92r: "By hanc Methodum therefore he did not therefore understand the method of Slusius but another Method which readily gave the method of Slusius; & this was the Method of D^{r} Barrow. For D^{r} Barrow thus describes his own method … These were D^{r} Barrows Rules, & these Rules are followed [illeg] by M^{r} Leibnitz ... D^{r} Barrow used the letters a & e. M^{r} Leibnitz \tells us that he/ chose rather to use the symbols dx & dy for the pretending \for/ the reasons here set down. But|And| if his calculations in drawing of tangents be compared wth those of D^{r} Barrow they will be found the same without any other difference then that of the symbols".

[336] See M. Feingold, *Newton, Leibniz, and Barrow too*, pp. 324-331.

Secondly, the word master can be considered in a deeper sense as indicating a person who, invested with authority, aimed at transmitting a certain view to selected and chosen disciples. The consideration of the specific case with Newton, makes of Barrow a master – Newton's master – in this second meaning, too. Not only did he provide his pupil with a technical mathematical training; Barrow also had a fundamental role in transmitting to Newton specific techniques and approaches in the mathematical sciences. This can be discerned in two different but related issues: the first one, consisted in Newton's geometrical view of the mathematical sciences. Barrow instilled in his student the conviction that mathematics was foundational to natural philosophy, sharing with him the idea that the world was written in mathematical figures; that one needed mathematics to understand it; that natural philosophy had mathematical principles; that God was a geometer *sans pareil*. The second issue concerned Newton's kinematical approach of "Resolving Problems by Motion". These two points, which seem to have been inspired by Barrow's approach, determined Newton's achievements in the field of mathematics; it is their extension to the consideration of the natural world, however, that makes of Barrow's impact on Newton's education a fact of the greatest importance.

In line with the 17th-century epistemological revolution, which connected inextricably mathematics and natural philosophy, Barrow tried to promote among his students the need to think about the natural world in geometrical and kinematic terms. His investigation of continuous magnitudes, indeed, was not confined to the resolution of mathematical problems; it involved the whole realm of nature. According to Barrow, the object of mathematics consisted in geometrical magnitudes generated by motion; and since continuous magnitudes affected all things, there was no part of physics that could be not reduced to geometry. The geometrical language of mathematics shaped the physical world and determined its study.

This concept perfectly matched Newton's ambition to become a "geometrical philosopher"[337] and to investigate the natural world in strict relation to this mathematical view. In

[337] A. E. Shapiro (ed.), *The optical papers of Isaac Newton* (Cambridge, 1984), pp. 87-89, and 437-439.

the course of his life, he developed such a project and achieved results that very few people were able to understand – but that many could nonetheless recognize as exceptional. The key to disclosing Newton's work resided in that geometrical and kinematic perspective of the world that Barrow transmitted to his promising student in Cambridge; Newton embraced, developed, and enhanced that view.

On the other hand, however, it is important to stress the fact that Newton did not form part of a "Barrovian school" even if he adopted similar mathematical techniques and approaches to Barrow, and even if he agreed with him that natural philosophy should have mathematics at its core. In an important sense, Newton exhibited and exemplified what it took to be the ideal behaviour of a disciple; but he also exercised great independence from his master. Barrow, on his part, nurtured the independence and talent of his pupil. He was presented with a mathematical wunderkind; his role was to guide him and allow his capacity for independent research to flourish.

As I will show in the following chapters Newton's own development – his exemplary self – explains in part why he could not abide disciples *qua* disciples. When he was a student in Cambridge, he did not display the features of a real disciple with respect to Barrow and, at least in principle, he did not overtly expect his acolytes to do the same. As he expressed in a letter to Nathaniel Hawes dated 25th May 1694,[338] his ideal student learnt basic notions and then, by engaging in hard work, was equipped to be truly independent. This is relevant for the analysis of why Newton became so opposed to Leibniz's deployment of disciples in spreading the Leibnizian word, although it does not clarify his apparent hypocrisy in making use of his own acolytes.

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[338] *NC*, Vol. 3, pp. 359-60

CHAPTER 5

NEWTON'S CIRCLE OF WOULD-BE DISCIPLES

Newton's pedagogical commitment in Cambridge

The appointment to the Lucasian professorship in Cambridge was a crucial event in Newton's career and it had important consequences for his intellectual activity at different levels. Firstly, the new role gave the young mathematician an institutional voice, authority, and visibility – a fact that had a huge impact on the circulation of his name and, consequently, on the acknowledgement of his achievements within the scientific community. Secondly, the stability offered by such a position allowed Newton not only to pursue his research in mathematics, optics, and natural philosophy but also to explore other fields like alchemy and theology. Finally, that commitment enabled Newton to engage in his pedagogical duties, an aspect that from a long-term perspective had important implications on the development and dissemination of his own work.

Understanding Newton's role as Lucasian professor in Cambridge is not an easy task. The scarcity of documentary traces accounting for this aspect of his career provides details neither about his teaching nor about his interaction with the students. A close analysis of different sources, nevertheless, helps to provide a profile of the general traits of his commitment to lecturing and teaching more broadly. In the well-known account narrated by Humphrey Newton, Newton's experience as Lucasian professor was depicted as a that of a solitary scholar who "for want of Hearers, read to the Walls".[339] At the time, professors were only obliged to give a small number of lectures each year, while the difficulty that the lectures presented to undergraduates in both Oxford and Cambridge almost certainly contributed to the sparsity of the audience.[340] This issue undoubtedly played a role in Newton's work as an instructor, but the image of a withdrawn

[339] MS Keynes 135, fol. 2.
[340] P. Allen, "Scientific Studies in the English Universities of the Seventeenth Century", *Journal of the History of Ideas*, vol. 10, no. 2 (Apr., 1949), pp. 219-253, p. 242.

professor who held his lectures in deserted classrooms, however accurate it was, does not mean that he was not involved – or not interested – in other aspects of his pedagogical role.

Within a few months of assuming his role as Lucasian professor, Newton undertook a major project aimed at producing a new algebra for students. Editing mathematical books for students was not uncommon at the time; on the contrary, it represented a popular practice. After the Great Fire of London in 1666, moreover, the print sector had experienced a depression in the business;[341] the need to update the English market led several English mathematicians to write introductory books for students.[342] As we have seen, with the help of John Collins, Isaac Barrow had been actively involved in this activity before becoming the inaugural Lucasian professor. Newton's involvement emerged in his efforts to provide a commentary on a translation of a Dutch treatise on algebra by Gerard Kinckhuysen. Kinckhuysen's *Algebra ofte Stel-konst* was first published in Low Dutch at Haarlem in 1661 as an introductory treatise on algebra. Just one year earlier, the same author had edited under the title *De Gront der Meet-kons* a work on conic sections that his Dutch non-specialist readership – to whom the book was addressed – found hard to digest. At the time, Kinckhuysen realized, only a few possessed an appropriate mathematical background to cope with advanced topics like conic sections; an introductory volume on basic algebraic notions was essential for beginners to get the rudiments of that discipline.[343]

Before Newton became involved in the project, Nicolaus Mercator had provided a Latin translation of Kinckhuysen's *Algebra* at the request of William Brouncker, the first president of the Royal Society. Expanding the availability of mathematical texts for learners was an indication of the fast-changing nature of the discipline and its teaching. Newton evidently contributed to this enterprise as part of his pedagogical duty as Lucasian Professor. This aspect emerges clearly in the summer of 1670 in his correspondence with Collins concerning the revision of Kinckhuysen's

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[341] W. G. Bell, *The great fire of London in 1666* (London: John Lane, the Bodley Head, 1920).
[342] N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method* (MIT Press, 2009), p. 342. D. T. Whiteside (ed,), *The Mathematical Papers of Isaac Newton* (Cambridge University Press, 1967–81), vol. 3.
[343] C. J. Scriba, "Mercator's Kinckhuysen-Translation in the Bodleian Library at Oxford", *The British Journal for the History of Science*, 1964, Vol. 2, No. 1, pp. 45-58.

Algebra. Newton told Collins that he was interested in revising the text with a more accurate version of the reduction of a given problem into the form of an equation, which was in his opinion "the most requisite & desirable doctrine to a Tyro".[344] Similarly, in a letter dated 27th September 1670 Newton suggested that one ought to approach that same subject with a "generall Analyticall method"; in the Dutch version, Kinckhuysen had proposed to reduce a problem to an equation "by particular & contingent inventions, w^{ch} though many times more concise then a generall method would allow, yet in my judgment are lesse propper to instruct a learner, as Acrostick's & such kind of artificiall Poetry though never soe excellent would bee but impropper examples to instruct one y^{t} aimes at Ovidian Poetry".[345] Newton's intervention in the text aimed at providing a more accurate version of the text for the sake of learners and stressed the fact that teachers could more easily show how, by means of a general analytic method, students could reduce problems to equations.

Newton's commitment to writing handbooks for students can be seen in the style and function of a mathematical treatise he wrote soon after assuming the Lucasian Chair. Indeed, *De Methodis Serierum et Fluxionum*, is a sort of hybrid between an introductory text and an innovative mathematical treatise. Composed in 1670-71, this treatise was published posthumously in 1736 by John Colson, the fifth Lucasian professor in Cambridge. Colson's English translation and Newton's Latin original text make clear both the pedagogical purpose of the book and the nature of audience to whom it was addressed. Colson's preface explicitly affirmed that Newton conceived the book "to teach his disciples and followers upon what grounds they should proceed"; *De Methodis* was "intended by himself [sc. Newton] for the instruction of novices and learners".[346] Sixty years earlier, in his introduction, Newton had already manifested his intentions by explaining that he had composed the treatise "for the sake of young students in this Science".[347] Indeed, the pedagogical

[344] Newton to Collins, 16th July 1670, in *NC,* vol. 1, p. 34
[345] Newton to Collins, 27th September 1670, in *NC*, vol. 1 pp. 43-44.
[346] I. Newton, *The Method of Fluxions and Infinite Series: With Its Application to the Geometry of Curve-lines. By Sir Isaac Newton, translated from the Author's Latin Original Not Yet Made Publick. To which is Subjoin'd, a Perpetual Comment Upon the Whole Work, By John Colson*, *Sir Isaac Newton. Henry Woodfall; and sold by John Nourse* (1736), Preface.
[347] *Ibid.*, Introduction.

nature of the book can be discerned in its didactic approach; as Guicciardini puts it, Newton's style resembles "that of the craftsman seeking to make a novice become used to increasingly complex cases".[348] This statement finds confirmation in Newton's text, more specifically in its language: in explaining the first problem, the author addressed the *discentes* (learners), while from the second problem onward he referred to the *artifices* (skilled practitioners). This shift denotes Newton's care in structuring his mathematical treatise by taking into consideration the stages of the process of learning highly technical mathematical notions.

Besides Newton's involvement in the revision and production of mathematical texts for learners, his correspondence also provides interesting hints about his pedagogical activity. From a letter sent to him by Collins dated 30th April 1672, for example, we can infer that, as Barrow did before him, Newton probably used to lend texts to his students. In the letter in question Collins wrote to Newton to "be pleased to accept 2 small tracts of Honorato Fabry (whereof I had many sent over) which though of no use to your selfe, you may bestow on some of your Pupills".[349] We cannot know whether Collins's suggestion corresponded to Newton's real habits; this assumption nonetheless strengthen the hypothesis that Newton was not completely uninterested in cultivating a relationship with his students.

Another document that attests to Newton's commitment to pedagogical activity during the 1670s consists of a short correspondence with Thomas Horne, a student at King's College in Cambridge. On 22nd August 1676, the young pupil asked the Lucasian Professor to ease his doubts:

> I have lately tryed to looke into Cartes 3d booke of ye nature of aequations, thinking to understand what goes before by ye helpe of his rules delivered there: & I begin to hope I may by my owne strength, & I judge it is better to find one conclusion out than have 20 shewed me, wch made me deferr moving questions to you so long, & partly because I cannot move my many doubts in proper termes. But I know you are to good & wise to deride me.[350]

[348] N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method*, p. 193.
[349] *NC*, vol. 1, p. 146.
[350] *NC*, vol. 2, p. 86-7.

In this passage, Horne was probably referring to Schooten's Latin edition of Descartes's *La Géométrie* (1659-1661),[351] which dealt with the construction of solid and linear problems, and the solution of cubic and biquadratic equations. Horne's doubts presumably arose out of the lecture course on algebra (specifically equations and their geometrical applications) which Newton delivered between 1674 and 1675 at Cambridge. Beyond its technical content, Horne's passage represents a significant illustration of the difficulty caused to the learner and of the consequent interaction with his master. Newton, indeed, answered Horne's queries with a brief message containing some indications on those themes.[352]

Mathematical texts and correspondence provide important evidence of Newton's perspective as a master. Yet, only three students – William Whiston, Thomas Parkyns, and Henry Wharton – left traces of their direct interaction with Newton during thirty-two years of his professorship. Whiston, Newton's successor as Lucasian professor, encountered him while an undergraduate in Cambridge in the late 1680s, having entered Clare College as a sizar in 1686. As reported in his memoirs, Whiston heard "one or two" of Newton's mathematical lectures – lectures that, he later admitted, he understood "not at all at the time".[353] Thomas Parkyns entered Cambridge in 1680 and mentioned Newton as his "Mathematick professor" in his *Progymnasmata*.[354] According to this account, though a fellow commoner, Parkyns was invited by Newton himself to his "publick lectures" at Trinity. Finally, Henry Wharton was a student in Cambridge from 1680 to 1687. According to his biographer, Wharton acquired "no mean skill in *Mathematicks* ... by the kindness of Mr. *Isaac Newton* … who was pleased to give him further instructions in that noble Science, *amongst a select Company in his own private Chamber*".[355]

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[351] F. van Schooten, *Geometria a Renato des Cartes anno 1637 Gallice edita* (Amsterdam, 1659-1661).
[352] *NC*, vol. 2, p.187.
[353] W. Whiston, *Memoirs of the life and writings of William Whiston* (1748) p. 32; S. D. Snobelen, "William Whiston, Isaac Newton and the crisis of publicity", *Studies in History and Philosophy of Science*, 35 (2004) 573–603.
[354] T. Parkyns, *Progymnasmata. The Inn Play, or Cornish Hugg Wrestler, digested in a method which teacheth to break all holds and throw most falls mathematically; of great use to such who understand the small sword in fencing* (Nottingham, 1713), p. 12.
[355] H. Wharton, *Fourteen Sermons Preach'd in Lambeth Chapel … with and Account of the Author's Life. The Second Edition Corrected* (London, 1700), sig. A3v-A4r (Emphasis added).

The practice of giving further instruction to students in the master's chamber was not unusual at the time; on the contrary, even the *Statutum* suggested resorting to that practice when needed. What is interesting here, is the use of expressions like "select company" and "private chamber", and their relation to events that followed. The demand for mathematical expertise explains the expression "select company" – being talented and being trusted represented essential requirements to be selected by Newton and to be part of his circle. Newton's well-known secretive attitude toward the disclosure of his theories, then, justifies the expression "private chamber". Newton's room constituted his alchemical laboratory, but also the place where he kept his precious mathematical, philosophical, and theological manuscripts. As the reports of some of his students reveal, in the 1690s Newton's chamber became an exemplary space for the transmission of difficult truths the place where the master brought some of those most talented acolytes that had gained his trust to initiate them into the new philosophy.

The birth of Newton's circle of acolytes

A full understanding of Newton's willingness to cultivate acolytes requires a deeper analysis of his approach to publication. The first appearance of Newton's name as the author of a printed publication was in 1672. On 6th February of that year, he had sent a letter presenting the results of his research on the refraction of light through a prism to the secretary of the Royal Society Henry Oldenburg who, some days later, promptly published it in the *Philosophical Transactions*. The article was received with great applause for its author: Newton's "ingeniosity" was highly admired by most of the Royal Society's fellows who also appreciated his "high degree of francknesse in this matter and in the communication thereof". But there was not only praise, and in private Robert Hooke harshly criticized Newton's theory, giving birth to a bitter dispute that confirmed Newton in his distrust towards publication. If as a consequence of publication one was obliged to quarrel

instead of pursuing research and knowledge, silence – intended as a strategic withdrawal – was preferable.[356]

The wish to avoid involvement in criticism and disputes was certainly a powerful reason for Newton's attitude toward the uncontrolled dissemination of his works. But regardless of the details relating to the events following his first publication, it is important to consider Newton's adamant conviction that knowledge and truth should be communicated with caution and, preferably, only to a chosen, learned audience. In fact, he conveyed such a view to Oldenburg in the immediate aftermath of publishing his paper by revealing his fear of "exposing discourses to a prejudic't & censorious multitude (by wch means many truths have been bafled and lost)". Indeed, he continued in the missive to Oldenburg, he had actually "designed it [sc. the letter on "Light and Colors"] onely to those that know how to improve upon hints of things" – presumably a select group within the Royal Society, as he was aware that it was "too straight & narrow" for a "publick view".[357]

Newton's willingness to control – and limit – the transmission of philosophical and mathematical doctrines shaped his strategy of dissemination, which consisted in circulating ideas and findings through letters and manuscripts. This practice, known as scribal publication, was not unusual in the middle of the seventeenth century; on the contrary, it was very popular among mathematicians. Together with other advantages, it allowed claiming priority without, at the same time, disclosing the core results to a broader and possibly hostile readership. Also, it allowed a mathematician to retain the capacity to make further discoveries on the basis of his work. Even the circulation via scribal publication, however, was difficult to manage and conflicted with the public

[356] R. Iliffe, "Butter for Parsnips. Authorship, Audience, and the Incomprehensibility of the Principia", in M. Biagioli & P. Galison (eds.), *Scientific Authorship. Credit and Intellectual Property in Science* (London: Routledge, 2003), pp. 33-65.

[357] A narrative of these events is provided by R. Westfall, *Never at Rest. A Biography of Isaac Newton* (Cambridge University Press, [1980] 1983), pp. 238-252. Quotations are from the correspondence between Newton and Oldenburg from 6th to 10th February 1672, in *NC*, vol. 1, pp. 92-109.

legitimation of knowledge promoted by contemporary natural philosophers like Robert Boyle and by the advent of academies and erudite journals.[358]

The need to balance print and scribal publication characterized Newton's scientific production throughout his whole life. When he decided to publish his *Principia*, he wanted to be recognised as a great natural philosopher. To some degree, he accepted that he was living in a new world, where scientific and mathematical claims had to be published to acquire credibility. Nonetheless, he conceived an apparently incomprehensible book dealing with an abstruse and counter-intuitive idea – the universal gravitation – in a mathematical language that only a few were able to read.[359] How could such a work acquire a competent audience, and ultimately credibility? The answer to this question resides in his commitment to and strategy for disseminating knowledge via the medium of select acolytes; the acknowledged technical difficulties of his work required trained people able to interpret it and proselytise on its behalf. Discipleship became the privileged agency by which Newton could maintain authorial distance, obtain credibility, and communicate elite knowledge through trusted intermediaries to a wider audience.

The first edition of the *Philosophiae Naturalis Principia Mathematica* appeared in the summer of 1687, and a series of comments and reviews ensued, accompanied by praise for both the work and its author. The technical depth of the treatise did not remain unnoticed; on the contrary, most of the reactions to the *Principia* stressed its complexity and even its unintelligibility. The main reason for this reaction consisted in the mathematical nature of Newton's work: although it was a work of natural philosophy, with mastery of, but not a pioneering deployment of mathematical techniques, for the most part, the understanding of Newton's *Principia* required a deep knowledge of authors like Euclid and Apollonius and of their mathematical works. In line with the

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[358] On Newton's scribal publication see R. Iliffe "'Is he like other men?': the meaning of the *Principia mathematica*, and the author as idol", in G. MacLean, ed., *Culture and society in the Stuart Restoration: literature, drama, history* (Cambridge, 1995), pp. 159-78. N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method*, pp. 339-364.
[359] N. Guicciardini, *Reading the Principia: the debate on Newton's mathematical methods for natural philosophy from 1687 to 1736* (Cambridge University Press, 1999), pp. 99-108.

epistemological reformation initiated by Copernicus and his 17th century followers, Newton made mathematics the privileged language of natural philosophy.

Being a mathematician was a mandatory requirement to read and understand the technicalities of his work and that was the reason why most of the "philosophers without mathematics"[360] could not digest its esoteric contents.[361] Newton himself stressed this point; when the Earl of Halifax approached him and asked "if there was no method to make him master of his discoveries without learning mathematics, Sir Isaac said No, it was impossible".[362] As he famously told William Derham, Newton preferred "to avoid being baited by little smatterers in Mathematicks"; and for this purpose, he "designedly made his *Principia* abstruse; but yet so as to be understood by able Mathematicians, who imagined, by comprehending his Demonstrations, [sc. they] would concurr with him in his Theory."[363] Among the lines of this last sentence, we can discern Newton's commitment to the cultivation of an elite band of expert disciples who, after mastering his demonstrations would contribute to affirm and establish his mathematical natural philosophy.[364]

The period following Newton's publication of the *Principia* naturally coincided with the emergence of his first acolytes. His astonishing achievement worked as a magnet and attracted the attention of a variety of mathematicians and natural philosophers who sent him their letters of praise from all over Europe. Not all of the senders received back Newton's regards; some of them, instead, were rewarded with little more than a simple note of acknowledgement. What criterion did Newton follow in order to select the people that would enter his inner circle of acolytes? Providing a general answer that works for each of Newton's would-be disciple is not possible. The analysis of several

[360] Halley to Newton (29 June 1686), in *NC*, vol. 2, p. 443.
[361] *N*. Guicciardini, *Reading the Principia,* pp. 169- 194.
[362] King's College, Cambridge, MS Keynes*,* 130.5, no. 2, p. 4.
[363] MS Keynes, 133.10.
[364] Derham's use of the word "demonstration" might not represent a random choice. Newton was convinced that the mathematics of the Ancients that he aimed at restoring was the only one able to provide geometrical demonstrations, whereas the mathematics of the moderns consisted only of a heuristic tool. In the process of indoctrination of his disciples, the adoption of his method constituted a crucial point.

cases provides nonetheless enough material to identify two main features required to be part of his favoured circle.

Firstly, although it was not necessary to be a mathematical adept to gain Newton's approval and patronage, all of his would-be disciples had received advanced education in that discipline. Samuel Clarke, for example, was educated in Cambridge as a theologian, but he could nonetheless read Newton's works and go deeply into both his mathematics and physics. Nevertheless, in most cases, the acolytes introduced themselves to the master – directly or via a trusted intermediary – by showing their advanced abilities in mathematics. This was the case of the Scottish mathematician David Gregory, who on 9th June 1684 – that is, before Newton had begun the research programme that would lead to the *Principia* – enclosed his mathematical treatise *Exercitatio geometrica de dimensione figurarum* in his first letter to Newton. Similarly, in his own initial letter to Newton, Roger Cotes introduced himself by discussing a difficult corollary – Corollary 2 to Proposition 91 of *De Quadratura* – that would prove his advanced mathematical skills.[365] Having disciples well-versed in mathematics played a crucial role in the priority dispute with Leibniz, especially after the 1700s, but it was likewise essential for developing and establishing the new natural philosophy as proposed in the *Principia*.

The ability to digest the technicalities of Newton's work was strictly connected to the second condition required to enter his circle of acolytes, which consisted in a staunch adherence to his system of the world. A true disciple needed to be prepared to believe in the approach to natural philosophy that Newton articulated in the *Principia Mathematica*, and to absorb and defend its core doctrines and principles. Except for David Gregory and John Craig – who were initially concerned with Newton's mathematics – all of Newton's acolytes approached the master after having read the *Principia* with irrepressible enthusiasm. Abraham De Moivre was so avid for reading it, that after purchasing a copy he cut up its pages so that he could carry a few with him at all times. All the

[365] R. Cotes to I. Newton, 18th August 1709: "Some days ago I was examining the 2d Cor: of Prop. 91 Lib. I and found it to be true by ye Quadratures of ye 1st and 2d Curves of the 8th Form of ye second Table in Yr Treatise *De Quadrat*." See N. Guicciardini, *Reading the Principia*, p. 184.

would-be disciples manifested to Newton their high praise for his outstanding work, but they also expressed their willingness to improve it or cleanse it of errors – the ultimate display of reverence was of course to offer to be an editor of a second edition. A key tactic for ingratiating oneself to the privileged set of acquaintances that surrounded Newton was to show errors in, or possible improvements to the *Principia*. Would-be acolytes made an implicit commitment to keep any errors secret – but also to make its contents more intelligible to a wider audience – a feature that would become the central focus of their agenda.[366]

A final condition for joining his inner circle consisted in making ardent expressions and displays of admiration for Newton himself. This sentiment was initially manifested as a mere sign of praise or respect. After reading the *Principia*, David Gregory wrote to Newton that he "justlie deserve the admiration of the best Geometers and Naturalists, in this and all succeeding ages", while Fatio De Duillier often described Newton as the ablest mathematician who had ever lived.[367] What made of a mere admirer an actual disciple, however, was the evolution of such vehement admiration into total devotion. Why did Newton's acolytes crave discipleship? Presumably, it was the novelty, or the apparent power, authority, and verisimilitude of Newton's work that attracted them to the master. Being associated with Newton, indeed, had important implications that defined not only the disciples' intellectual orientation but also their institutional status. When they took on the commitment, the disciples chose to dedicate both their work and their life to Newton's cause. They did so in different ways and to a different degree, but with the ultimate reward of being allowed into his *sanctum sanctorum*.

The would-be disciples' initiation into Newton's intellectual world

Once that the would-be disciples had been selected and had gained Newton's esteem and trust, the process of initiation began. Before meeting the master, most of the acolytes had received a

[366] Both Fatio De Duiller and David Gregory produced a list of *errata* and *corrigenda* to integrate into a projected second edition of the *Principia*.
[367] F. Manuel, *A portrait of Isaac Newton* (London: Frederick Muller Limited, 1980), p. 193.

mathematical education – thus, they could understand most of Newton's work without his help. What they got through a more enhanced contact with him and his works was the membership of the core group – discipleship. The word "disciple", indeed, not only refers to a pedagogical acceptation; it is also used in the sense of absorbing and taking on certain opinions or principles. This close contact had reciprocal advantages: on the one hand, the would-be disciples could consult Newton personally – a privilege accorded to few; on the other hand, Newton could impart specific instructions to skilled mathematicians who would then act as trusted allies inside formal and informal milieus.

When the would-be disciples encountered Newton for the first time, they were not yet able to share all the nuances of his views. In the main this was because Newton deliberately kept these aspects hidden from his readership, but it was also because many of his more mature views did not yet exist. Indeed, as in the cases of Richard Bentley and Roger Cotes, the scolytes themselves often prompted Newton into careful and productive contemplation about the philosophical, scientific, and theological implications of his work. On some occasions, and notably in the case of David Gregory, the first step of the initiation consisted in a complete disclosure – or revelation – of Newton's corpus of knowledge to his acolytes. This process, which mostly took place in his chamber in Cambridge, involved discoveries in natural philosophy and mathematics, but in many cases it also embraced the acceptance of Newton's unorthodox theological views, his private interest in alchemy, and his belief in the so-called *prisca sapientia*.[368] The outcome was a total conversion to Newton's paradigm: the disciples not only adopted Newton's views, method, and language; they also developed a blind devotion to the divinized figure of Newton himself. A passage from William Stukeley's *Memoirs of Sir Isaac Newton's Life* provides a vivid image of such worship: "We always took care on Sunday to place ourselves before him, as he sat with the heads of the Colleges; we

[368] R. Iliffe, *Priest of Nature. The Religious World of Isaac Newton* (Oxford University Press, 2017), pp. 202-203

gaz'd on him, never enough satisfy'd, as on somewhat divine... drawn forth into light before, as to his person, from his beloved privacy in the walls of a college."[369]

David Gregory's case illustrates thoroughly how an individual was selected, initiated, and converted to the Newtonian creed. As noted above, the first contact between Gregory and Newton happened in June 1684, when the former – then professor of mathematics in Edinburgh – wrote to the Lucasian professor and asked him for "free thoughts" on his mathematical treatise *Exercitatio geometrica de dimensione figurarum*.[370] Gregory's missive remained unanswered – but not unnoticed.[371] Probably, on that occasion, Newton was not particularly impressed by Gregory's mathematical skills, and indeed the *Exercitatio geometrica* consisted mainly in a reorganization of the work of his uncle, James Gregory, on quadratures.[372] A second letter followed on 2nd September 1687, in entirely different circumstances, when Gregory wrote to Newton to compliment him on his *Principia*. Newton, again, did not reply to this letter, though he certainly appreciated Gregory's flattery. The young mathematician highly praised Newton's work not only for the "improvement made by you in the Geometry" but also for its "unexpectedlie successful" application "to the physics"[373] It was only after 1688 that a conflict between the two mathematicians turned into a real opportunity to become closer: in that year, Gregory allowed his friend Archibald Pitcairne to publish his (Gregory's) reverse engineering of the binomial theorem. Gregory's work relied on the use of notes on Newton's quadrature (integration) techniques that John Craig had taken when visiting Newton in 1685. That publication provoked Newton's

[369] W. Stukeley, *Memoirs of Sir Isaac Newton's Life*, edited by A. Hastings White (London: Taylor and Francis, 1936), p. 10.
[370] *NC,* vol. 2, p. 396.
[371] After receiving the letter, Newton promptly composed a dossier – *Matheseos Universalis Specimina* – that would prove his priority over the discovery of a particular case of his binomial theorem.
[372] In the late 1660s and 1670s, James Gregory and Isaac Newton were dealing with the same problems in calculus – specifically, they were producing infinite series solutions to a wide range of problems. Eventually, they figured out similar methods. Gregory, however, died suddenly in October 1675. The papers containing his mathematical results were inherited by his brother David, who was the father of the David Gregory who became Newton's disciple. David jr.'s first attempts to tackle his uncle's work dates to 1682.
[373] *NC*, vol. 2, p. 484.

reaction but was also essential to establish a contact between them and, eventually, to enrol Gregory among Newton's would-be disciples.[374]

Gregory first tried to establish contact with Newton as an equal; after digesting the contents of the *Principia,* however, he became aware that the only way to get closer was to defer to him. On the other hand, when Newton realised that Gregory was working on similar mathematical questions, not only did he try to secure priority over his method, but he also understood the need to have mathematicians like Gregory by his side.[375] Gregory, indeed, epitomized all the characteristics that Newton would seek in his disciples. These features are neatly described in the letter of reference that Newton submitted to support Gregory's candidature to the Savilian chair of Astronomy at Oxford on 27th July 1691:

> I do account him prudent sober industrious modest & judicious & in Mathematiques a great Artist. He is very-well skilled in Analysis & Geometry both new & Old. He has been conversant in the best writers about Astronomy & understands that science very well. He is not only acquainted wth books but his invention in mathematical things is also good. He has performed his duty at Edinburgh wth credit as I hear & is respected the greatest Mathematician in Scotland & that deservedly so far as my knowledge reaches. For I take him to be an ornament to his Country & upon these accounts recommendable to the Electors of the Astronomy Professor in Oxford now vacant.[376]

Newton's support of Gregory for the Savilian chair had a twofold purpose: firstly, the master intended to manifest his commitment to the would-be disciple – in this sense, Newton's support can be intended as a sort of reward for Gregory's alleged loyalty, a strategy to make of Gregory an ally. Secondly, populating the most important academic positions with his acolytes would be strategically essential for Newton to establish and spread the new philosophy. Obtaining the Savilian chair for Gregory, ultimately, represented an act of reciprocal trust in the relationship.

A crucial moment for the relationship between Gregory and Newton took place in Cambridge, where the two spent four days together – from 4th to 8th May 1694. At the time, the

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[374] P. Beeley, «'There are great alterations in the geometry of late'. The rise of Isaac Newton's early Scottish circle», *British Journal for the History of Mathematics*, 35:1, pp. 3-24.
[375] It was Gregory himself that in 1688 had allowed his friend Archibald Pitcairne to publish his (Gregory's) theorem on the quadrature of curves. Gregory's work relied on the use of notes on Newton's quadrature (integration) techniques that John Craig had taken when visiting Newton in 1685. See R. Westfall, *Never at Rest*, pp. 469-70 (esp. 470) and 510-20 (esp. 513-15).
[376] *NC*, vol. 3, pp. 154-55.

Scottish mathematician was already a fervent Newtonian: in the previous years he had annotated thoroughly Newton's *Principia* with mathematical expertise and had begun to disseminate his master's views on natural philosophy. For example, although the content of Gregory's lectures at Oxford was not overtly aimed at defending the Newtonian system, Newton's theories – especially universal gravitation – were accepted *tout court*.[377] It was only after spending time in Cambridge, however, that he became a staunch disciple. From Gregory's memoranda, we learn that during their encounters Newton disclosed to the young mathematician his entire intellectual production. Their discussion ranged over a wide variety of subjects like the Gospel of John, "the higher geometry of the Ancients", "the gravity of the Moon to the Earth, and of the planets to the Sun", the properties of conic sections, reflexion or refraction, "the Quadratures of Curves", the Mosaic religion and many other topics. Gregory, for his part, treasured every single word pronounced by his master; most of the writing of his notes appears to be hurried but still clear and detailed.

Those four days in Cambridge resulted in a total conversion to Newton's interests, language, and method. After May 1694, Gregory was deeply persuaded of the superiority of the "Ancients" and profoundly convinced about the importance of rediscovering the *prisca sapientia*. In July of that same year, when he was confident that his "Notes on the Newtonian Philosophy" would be published, he planned to append to the new edition of the *Principia* a text explaining "the authentic design of the Ancients", in which "the errors of the moderns about the mind of the Ancients are detected".[378] This project was never realized by Gregory – the editorship of the second edition of the *Principia* was eventually assigned to Roger Cotes. But he nonetheless kept developing Newton's interests in the Ancients by publishing in 1703 an edition of all the known works which

[377] C. M. Eagles, *The Mathematical Work of David Gregory, 1659-1708* (PhD thesis, University of Edinburgh).
[378] R. Iliffe, «"Is he like other men?": the meaning of the Principia Mathematica, and the author as idol», pp. 159-78.

had been attributed to Euclid,[379] and by projecting the edition of Apollonius's works which, however, was never accomplished in Gregory's lifetime.[380]

Besides these editorial projects in the wake of Newton's interests, Gregory also converted his mathematical style, adopting his master's language and method. After 1694, he began to use exclusively the dot notation for differentiation, which Newton had only recently deployed for the first time. Also, he adopted Newton's method of fluxions and fluents and its related terminology. This was an essential change: the would-be disciple had to align with his master to be integrated into his circle. During that last decade of the 17th century, moreover, the relationship between Newton and Leibniz was beginning to sour and their respective schools of thought were beginning to dispute not only the priority of the discovery but also the superiority of their methods. Promoting and enhancing Newton's way in his own style would become an essential part of his disciple's strategy.

Gregory's conversion to the Newtonian system – which included mathematical techniques, general attitudes, and specific concepts – reveals important aspects of the transformation of a skilled mathematician into a trusted disciple. His case was certainly peculiar, but it was not isolated. A similar process – though under different circumstances – involved the Swiss mathematician Nicolas Fatio de Duiller. Like Gregory, Fatio was a fervent Newtonian even before meeting the master; his enthusiasm increasingly developed from a rigorous and passionate reading of the *Principia*. The first meeting with Newton took place at the beginning of 1689 in London, where Fatio had arrived

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[379] While preparing this edition, Gregory consulted Newton several times about Pappus' *Collection*. Master and disciple also corresponded about its preface. In May 1703, for example, Gregory asked Newton whether he should put all Pappus' comments on the Porisms into his preface. Eventually, the preface dated 10th June 1703 did not include that description, meaning that probably Newton did not answer in time. In a later letter, he expressed his wish to include it with Commandino's translation for the sake of completeness. C. M. Eagles, *The Mathematical Work of David Gregory,* p. 74

[380] Gregory worked on the edition of Apollonius's works in conjunction with Edmund Halley, his Savilian co-Professor of Astronomy. Following Gregory's death in 1708, the work was completed by Halley, who published it in 1710 with the title *Apollonii Pergæi Conicorum libri octo: et Sereni Antissensis De sectione cylindri & coni libri duo. Oxoniæ: e Theatro Sheldoniano, An. Dom. MDCCX*. See R. Wilson, *Oxford's Savilian Professors of Geometry: The First 400 Years* (Oxford: Oxford University Press, 2022), pp. 55-92.

two years earlier as an intermediary between the English milieu and Christiaan Huygens.[381] During that encounter, Newton presumably was highly impressed by the talented mathematician; a few months later, indeed, the two exchanged some letters with a colloquial and friendly tone that the Lucasian professor rarely reserved for his correspondents.

After that first encounter, Newton and Fatio planned further meetings, as a letter dated 14th February 1692/3 shows. Newton was about to go to London and wrote to Fatio that he would "be very glad to be in ye same lodgings" with him; "I will bring my books & your letters wth me", continued Newton in his brief missive, as to intend that they'll spend their time discussing privately their common interests.[382] On that occasion, the topic of their conversation was presumably alchemy, as implied by the reference to Boyle that follows in the letter.[383] From several missives that Fatio sent to Huygens to report his activity in London, however, we learn that, as it was for Gregory, during their private encounters Newton disclosed to Fatio his entire intellectual repertoire. In a letter dated 19th February 1692,[384] for example, Fatio expressly told Huygens about Newton's belief in the *prisca sapientia*, and he also referred to Newton's mathematical work with words that imply Newton's total disclosure of his most recondite achievements on that topic. Fatio expressed his conviction about Newton's priority over the invention of the calculus and complained about the latter's disrespectful attitude in not quoting Newton on the topic. In confronting the two authors, indeed, one could easily discern "leur difference comme d'un original achevé, et d'une copie estropiée et tres imparfaite". Fatio was already a loyal disciple, convinced of Newton's superiority over every other contemporary mathematician, and he was persuaded that Newton's method was "infiniment plus general que tout ce que l'on avoit auparavant, et il est tres simple et d'un usage merveilleux dans toutes les parties de la Geometrie". Fatio's use of expressions like, "la fluxion de

[381] R. Iliffe, "Servant of Two Masters: Fatio de Duillier between Christiaan Huygens and Isaac Newton", in E. Jorink, A. Maas (eds.), *Newton and the Netherlands: how Isaac Newton was fashioned in the Dutch republic* (Amsterdam: Leiden University Press, 2012), pp. 67-91.
[382] *NC*, vol. 3, p. 245.
[383] *NC*, vol. 3, pp. 265-67. On their common interest in alchemy see L. Maddaluno, "Four Unpublished Letters from Nicolas Fatio de Duillier to Isaac Newton", *Nuncius*, 34 (2019), 661–702.
[384] *NC*, vol. 3, p. 196.

la fluxion, ou la fluxion de la fluxion de la fluxion", moreover, signalled the success of his initiation and conversion respectively into Newton's circle and language. In replying to Fatio's letter, indeed, Huygens, who was not part of that circle, manifested his difficulties in understanding that language: "Au reste je n'entens pas ce que signifie la fluxion de la fluxion; il semble que cela veuille dire la tangente d'une ligne courbe dont depend la courbe de la premiere fluxion mais je ne vois pas alors en quoy la difficulté devient plus grande."[385] Once Fatio adopted Newton's mathematical language, his dialogue with Huygens became possible only by assuming the role of a translator mediating between two different paradigms.

The analysis of Gregory and Fatio's initiation into the Newtonian system provides significant evidence concerning the increasingly sectarian nature of Newton's circle of disciples. As a new Pythagoras, Newton was profoundly convinced that natural knowledge and mathematical discoveries had to be revealed only to worthy and talented initiates. For this reason, he selected and chose his acolytes by following strict criteria. When the tyros had gained his trust, he revealed to them his unpublished theories and his unorthodox ideas. This process was always characterized by a sort of secrecy and impenetrability that resembled the Pythagorean cult. Unlike Pythagoras, however, Newton had to keep up with his time and its practices, which included wider dissemination of scientific findings and discoveries. For the last task, his disciples were called upon to spread Newton's word.

Evangelization

Meeting Newton represented a turning point for many of the disciples' intellectual life; their efforts were then focused on cultivating and disseminating the master's interests, methods, and goals. The evangelization of Newton's gospel concerned three main spheres: natural philosophy; the foundational concepts of his philosophy; and the method of fluxions. The

[385] *NC*, vol. 3, p. 196.

disciples participated differently in the accomplishment of this mission, each focusing on one or more aspects of Newton's enterprise but all united by the common purpose of establishing the master's authority within formal and informal milieus.

Natural philosophy represented a cardinal aspect of Newton's agenda. The edition, revision, and publication of the *Principia*, where the mainstream of his research on this subject was published, occupied Newton from the 1680s to 1726, when the third edition was issued. The *Opticks* represented another important project of this kind: the book appeared first in 1704, followed by a Latin edition in 1706 and by a revised English edition in 1717. The disciples' role in the realization of these projects was central not only in the process of publication but also in the correction, revision, and expansion of Newton's theories, by which process they turned his works into canonical productions, making Newton a great author and decoder of God's natural language. Also, they were fundamental in the dissemination of Newton's natural philosophy among specialized and non-specialized audiences.[386]

David Gregory was one of the most active acolytes involved in the discussion of natural philosophy with the master. Both the compilation and revision of his *Notae in Isaaci Newtoni Principia Mathematica Philosophiae Naturalis*[387] provide important elements for understanding the metamorphosis of a passionate follower into a fervid disciple. When he drew up the notes between 1687 and 1694, Gregory had not yet met Newton and probably compiled those thorough and detailed comments only to clarify difficult passages of the text for his own convenience.[388] Certainly, in their original form, the notes were not intended to be shown to Newton: Gregory's tone was rather critical and highlighted errors and misprints. Also, he attributed a number of Newton's results to other mathematicians like James Gregory, Christiaan Huygens and himself. In

[386] A. R. Hall, "Correcting the Principia", *Osiris*, 1958, vol. 13, pp. 291-326. I. B. Cohen, *Introduction to Isaac Newton's Principia* (Harvard University Press, 1978).
[387] C. M. Eagles, *The Mathematical Work of David Gregory, 1659-1708*. I. B. Cohen, *Introduction to Newton's Principia* (Cambridge, 1971), pp. 40-42.
[388] Gregory drew up similar notes on Huygens' *Horologium Oscillatorium.* C. M. Eagles, *The Mathematical Work of David Gregory, 1659-1708*, p. 27-28.

discussing Proposition 6 of Book 1, for example, he reworked Newton's demonstration following Huygens's path – which presumably appeared to him more rigorous or clearer. At the time Gregory was a convinced follower of Newton's natural philosophy; he was interested in Newton's set of ideas and admired his work. Only after being introduced to the inner circle, however, did he become a staunch disciple that unfalteringly believed in Newton's theories. After 1694, indeed, he revised his *Notae* with a completely different attitude and tone. In the additional notes written on slips of paper and affixed to the text with a paste of wax, Gregory retracted most of the emendations that he had previously made. Proposition 6 of Book 1, for example, returned in its original formulation, as Newton published it in the first edition of his *Principia*.[389]

Gregory's *Notae* are important both for understanding his conversion to Newton's natural philosophy, and for assessing his preparedness to contribute to and participate in its establishment and dissemination. As soon as he was told by Newton about his intention to publish a revised edition of the *Principia*, Gregory began to work on the project of appending his *Notae* to the main text. We cannot know whether Newton ever considered Gregory's proposal to publish his notes – a proposal that the Scottish mathematician advanced in May 1694 in Cambridge – but we know its outcome: the text remained unpublished. On the other hand, in 1702 Gregory edited a book, the *Astronomiae physicae & geometricae elementa*, that provided a thorough account of those parts of the *Principia* that dealt with cosmology and planetary theory. Gregory's text was the first mathematical introduction to Newton's natural philosophy to be published and represented his public declaration of faith in Newton's system. It was also the first step of a strategy of dissemination that aimed at reaching a wider – though still learned – audience.

Gregory was not the only disciple to propose his candidacy for the role of editor of a new edition of Newton's *Principia*. In a letter dated December 1691, Fatio De Duillier explained to

[389] N. Guicciardini, *Reading the Principia*, p. 179-184.

Huygens his intention to pursue that project as well as the reasons that made him a perfect candidate for the role:

> Il est assez inutile de prier Monsieur Newton de faire une nouvelle édition de son livre. Je l'ai importuné plusieurs fois sur ce sujet sans l' avoir jamais pu flechir. Mais il n'est pas impossible que j'entreprenne cette édition; à quoi je me sens d'autant plus porté que je ne croi pas qu'il y ait persone qui entende à fonds une si grande partie de ce livre que moi, graces aux peines que j'ai prises et au temps que j'ai emploié pour en surmonter l'obscurité. D'ailleurs je pourrois facilement aller faire un tour à Cambridge et recevoir de Mr. Newton même l'explication de ce que je n'ai point entendu. Mais la longueur de cet ouvrage m'epouvante, puis que par les differentes choses que j'y voudrois ajouter il feroit un folio assez raisonnable. Ce folio neanmoins se liroit et s'entendroit en beaucoup moins de temps que l'on ne peut lire ou entendre le quarto de Mr. Newton.[390]

This passage highlights two important aspects of being a disciple: firstly, both the intellectual and the physical proximity to the master was essential to collaborate on a certain project, especially when the project involved a highly technical mathematical competence. Secondly, the disciple made clear his intention to render Newton's work easier and more accessible to its readership. When Newton wrote the *Principia*, he was intentionally addressing a very selected and limited audience. However, he needed to reach – and convince – a wider readership to establish both the content of his work and the authority of its author. A new edition was needed and disciples like Fatio were the perfect candidate to edit its content and correct errors and misprints.

Why did Newton not comply with Fatio's proposal for republishing the *Principia*? The answer to this question probably resides in the divergence that emerged between Newton and Fatio regarding their respective explanations of gravity. At first, Newton seemed to be sympathetic to Fatio's mechanical theory based on the movement of ether particles. In a note dated 1691, even David Gregory reported this favourable inclination of the master toward Fatio's explanation. Just under that note, however, in a subsequent moment, Gregory added a further comment expressing Newton's disapproval of "Mr. Fatio's manner of explaining gravity".[391] Although Fatio agreed with his master on many issues, he nonetheless conceived a theory that was not exclusively

[390] *NC*, vol. 3, p. 186.
[391] S. P. Rigaud, *Historical essay on the first publication of Sir Isaac Newton's Principia* (Oxford University Press, 1838), pp. 89-95.

Newtonian in character and that he probably wished to promote through the second edition of the *Principia* – a risk that Newton did not take.[392]

This occurrence speaks loudly about the disciples' choice of sacrificing – or not – their intellectual autonomy in engaging with the elucidation or improvement of their master's work. In most cases, the disciples unconditionally devoted their publications to the master. Sometimes, however, they did not adhere wholly to his program, thus maintaining a sort of independence. As for his work, Fatio belonged to the latter category. Although he converted to Newton's view on many aspects, he nonetheless did not renounce his own theory of gravity – probably at the cost of curating the second edition of the *Principia*. On the other hand, in the early 1690s he committed himself to "sacrificing" his own life to live by his master's side. What was peculiar – and unique – in the relation between Fatio and Newton was a sort of closeness and intimacy that characterized their intercourse from the very beginning. The reciprocal need for proximity grew over the years, as it is traceable in their correspondence. In letters dating from the turbulent personal period in the early 1690s, Newton manifested his desire to have Fatio near to him on a number of occasions.[393] In turn, the Swiss mathematician revealed to his master that "if it was practicable and proper" he would "hire the chambers which You had next to Yours"[394] because, as he stated in a later letter, he wished "to live all my life, or the greatest part of it, with you, if it was possible".[395]

One of the main advantages of cultivating disciples, indeed, consisted in the possibility of establishing a mutual exchange of ideas with brilliant interlocutors. Newton profited from this arrangement, and the case of his relationship with Roger Cotes – to whom eventually he assigned the editorship of the second edition of the *Principia* – constitutes one of the most significative examples of how master and disciple discussed highly technical notions to accomplish the same ambitious goal. The close collaboration between Cotes and Newton on the second edition of the

[392] In a letter to De Beyrue in reply to Leibniz, Fatio clearly showed how his explanation merged Newtonian and Huygenian elements. *NC*, vol. 3, pp. 308-9.
[393] Newton to Fatio De Duillier, 14th February 1692/3. *NC*, vol. 3, p. 245.
[394] Fatio De Duillier to Newton, 9th March 1692/3. *NC*, vol. 3, p. 262.
[395] Fatio De Duillier to Newton 11th April 1693. *NC*, vol. 3, p. 391.

Principia began in 1709 when Richard Bentley introduced the former to the master as a perfect candidate for that task. Cotes, who only two years earlier had been elected as the first Plumian Professor of Astronomy and Experimental Philosophy in Cambridge, was an extraordinarily skilled mathematician and a fervid admirer of Newton's work.[396] No doubt, then, that he accepted the task with great enthusiasm, as the first letter to the master dated 18th August 1709 reveals: Cotes was "impatient" to receive a copy of the *Principia* annotated by Newton and "bound in gratitude" for that invaluable assignment.[397]

From October 1709 onwards, Cotes worked relentlessly on Newton's text. His first comments showed that he was not only skilled enough to study accurately the *Principia* but also adequately talented to propose keen suggestions to improve that second edition. From what we know, Cotes never visited Newton in London during the whole period of three and a half years, which means that master and disciple established a long-distance collaboration based on the regular exchange of missives on advanced mathematical topics. The subject of their correspondence, indeed, was often very technical. In his letters, Cotes systematically proposed to Newton "little alterations" in content, structure, and style to render the *Principia* easier, clearer, and complete.[398] In addressing Newton, his tone was always respectful but still firm and resolute. At the time of their collaboration the age gap between Cotes and Newton was forty years, with the former at the beginning and the latter at the peak of their respective careers. Notwithstanding this divide, Newton always responded to the young mathematician with regard and consideration, without imposing the weight of his age and authority.[399]

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[396] When he was sixteen, Cotes attended St Paul's School, where he showed precocious talent in both mathematics and astronomy. In 1699 he entered Trinity College at Cambridge where after his second year he demonstrated that he could handle fluxions. In 1707 he became the first Plumian Professor of Astronomy, being strongly favoured by the Lucasian Professor, William Whiston and by Richard Bentley. See *NC*, vol. 5, pp. XXI-LI (*Introduction*).
[397] *NC*, vol 5 p. 3. The correspondence between Cotes and Newton is also available in J. Edleston (ed.), *Correspondence of Sir Isaac Newton and Professor Cotes* (London, 1850).
[398] See *NC*, vol. 5, pp. 46, 67, 107-8.
[399] This appears more evident if we consider the exchange between the two mathematicians on Corollary 4, Proposition XV. On 29th April 1710, Cotes sent his considerations on this topic to Newton. The Lucasian professor at first replied by restating his convictions, while in a later letter he admitted Cotes's correctness on that point. *NC*, vol. 5, pp. 29,42.

The technical details discussed by Cotes in his letters to Newton demonstrate that mathematical expertise constituted a necessary condition to be part of Newton's inner circle. The most interesting aspect of their correspondence on the *Principia*, nevertheless, concerns Cotes's staunch adherence to the Newtonian paradigm and his consequent participation in the fight against Cartesians and Leibnizians. These elements can be traced in the exchange between Cotes, Newton, and Bentley concerning the drafting of the *Principia*'s preface. From the first letter that Cotes sent to his two correspondents on this topic, it is possible to discern his willingness to make of that preface a manifesto of the Newtonian program, with the additional aim of defending Newton's theory from the objections raised by continental mathematicians after the publication of the first edition. At the time of this exchange, the dispute with Leibniz was just breaking out and the young disciple was publicly lining up on Newton's side.

At first, Cotes did not know whether he was in charge of writing the text of the preface or whether Newton or Bentley were going to do so. In both cases, the preface would bear Cotes's signature. The interchangeability of their names represented an important aspect of the master-disciple relationship: on the one hand, the disciple showed to be ready to "own" and "defend" whatever Newton would affirm;[400] on the other hand, the master could state his opinion without at the same time exposing himself directly to the critics. Eventually, Cotes wrote the preface of the second edition of the *Principia*, though Bentley sent him Newton's instruction to do so:

> For ye subject of ye Preface, you know it must be to give an account, first of ye work it self, 2dly of ye improvements of ye New Edition; & then you have Sr Isaac's consent to add what you think proper about ye controversy of ye first Invention. You your self are full Master of it, & want no hints to be given you: However when it is drawn up, You shall have His & my Judgment, to suggest any thing yt may improve it. Tis both our opinions, to spare the Name of M. Leibnitz, and abstain from all words or Epithets of reproch: for else, yt will be ye reply (not that its untrue) but yt its rude & uncivil.[401]

Cotes welcomed Newton's direction to use the preface to introduce and enhance the novelties of the new edition. To this intention, moreover, the disciple proposed to add further evidence explaining

[400] In a letter dated 10th March 1712/13 Cotes wrote: "You may depend upon it that I will own it [sc. the Preface], & defend it as well as I can, if hereafter there be occasion". *NC*, vol. 5, p. 389.
[401] *NC*, vol. 5, pp. 390-1.

Newton's method and to demonstrate his principles, with the ultimate goal of rendering the *Principia* more comprehensible to a wider audience:

> I think it will be proper besides the account of the Book & its Improvements to add something more particularly concerning the manner of Philosophizing made use of & wherein it differs from that of De Cartes & others. I mean in first demonstrating the Principles it imploys. This I would not only assert but make evident by a short deduction of the Principle of Gravity from the Phaenomena of Nature, *in a popular way, that it may be understood by ordinary Readers* & may serve at the same time as a Specimen to them of the Method of the whole Book.[402]

In his letter, Cotes also referred to the fact that, as Newton suggested, he would not mention Leibniz in his Preface. Nonetheless, he asked his master "to appeal to ye Commercium Epistolicum to vouch what I shall say of Your Self, & to insert into my Preface the very words of the Judgment of the Society (page 120 Comm: Epist) that Foreigners may more generally be acquainted with the true state of the Case". Newton's reply to this proposal reveals part of the strategy that he was devising at the time to fight his battle against Leibniz. In concluding his letter dated 31st March 1713, he wrote to his disciple: "If you write any further Preface, I must not see it for I find that I shall be examined about it".[403] And in fact, after drafting it, Cotes showed his preface to Samuel Clarke and not to Newton for proofreading – though this distancing would not have fooled Leibniz.[404] The ongoing dispute with Leibniz probably led Newton to minimize his public acknowledgement to Cotes for the work that he had done in revising the second edition of the *Principia*.[405] In composing the Preface the disciple had nonetheless been fundamental in editing that text and to a limited degree, in popularizing Newton's natural philosophy. Notwithstanding Cotes's

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[402] In this passage, Cotes was specifically referring to the need of demonstrating – and not merely asserting – the principle (universal gravity) underlying natural phenomena. *NC*, vol. 5, p. 391 (emphasis added). A. Koyré, *Newtonian studies* (London, 1965), pp. 273-82. Cotes's intention to popularize the *Principia* can be also traced in a letter that the disciple wrote to William Jones, to whom in April 1713 he had sent a copy of the index. In the letter, Cotes explained that the index "was not design'd to be of any use to such Readers as Your self, but to those of ordinary capacity". J. Edleston (ed.), *Correspondence of Sir Isaac Newton and Professor Cotes*, p. 224.

[403] *NC*, vol. 5, p. 400. The letter "Ad Lectorem" prefixed to the second edition of the *Commercium Epistolicum* confirmed this version of the facts: "Quae novae Principiorum editioni praemissa sunt, Newtonus non vidit antequam liber in lucem prodiit". See J. Edleston (ed.), *Correspondence of Sir Isaac Newton and Professor Cotes* (1850), pp. 157-8. A similar account can be found in one of Newton's manuscript drafts: "The Preface of the Editor praefixed to the second Edition of my Book of Principles at Cambridge I did not see till the Book came abroad but [it seems to be in answer to M^{r} and I find what he saith there in relation to M^{r} Leibnitz is in answer to his accusing me of introducing occult qualities & miracles & therefor M^{r} Leibnitz is still the aggressor". CUL MS Add. 3968, f. 506.

[404] *NC*, vol. 5, pp. 412-15.

[405] On this theme see *NC*, vol. 5, pp. XXXIV- XXXIX.

effort, the mathematical contents of the second edition of the *Principia* were still highly technical and the gap between the master and his non-expert readership still wide.

Rendering Newton's natural philosophy accessible to a non-specialist audience was the goal that William Whiston aimed to realize in his life.[406] Whiston met Newton for the first time in the 1680s when he attended as a student the Lucasian professor's lectures in Cambridge. It was only in 1694, however, that he established a closer relationship with the master. After receiving the customary initiation,[407] the disciple began his enthusiastic mission of evangelization. Whiston's staunch adherence to Newton's views and his first attempts at its popularization can be traced among the lines of his first publication, *A New Theory of the Earth*. Completed in May 1696, this work aimed at demonstrating that biblical stories like "the creation of the world in six days, the universal Deluge, and the general conflagration, as laid down in the Holy Scriptures" perfectly agreed to reason, philosophy, and science. Whiston's work relied so much on Newtonian physics and astronomy that in reading certain passages it was difficult to determine the disciple's identity and originality. The intellectual closeness between master and disciple, indeed, did not go unnoticed: for example, the naturalist John Ray told Edward Lhuyd that Whiston's *New theory* "is borrowed of Mr. Newton in great part".[408] John Flamsteed blamed Whiston for having "copied all that he understood of M. Newtons Princi[pia]"[409] while in a similar vein, Archibald Pitcairne concluded that Whiston's *New theory* resembled very much "a paper given [sc. Whiston] by Mr Newton".[410]

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[406] J. E. Force, *William Whiston: Honest Newtonian* (Cambridge: Cambridge University Press, 1985).
[407] In his notes, Whiston revealed some hints about his indoctrination and recalled "some of the most valuable Intimations I formerly had from him [sc. Newton], during our Acquaintance, relating to certain sacred Matters of the greatest Consequence". W. Whiston, *A collection of authentick records belonging to the Old and New Testament* (London, 1728), Vol. II, p. 1071.
[408] R. W. T. Gunther (ed.), *The further correspondence of John Ray* (London, 1928), p. 277.
[409] E. Forbes, L. Murdin, F. Willmoth (eds.), *The correspondence of John Flamsteed, the first Astronomer Royal (1682-1703)*, (Philadelphia: Institute of Physics, 1997), Vol. 2, p. 827.
[410] W. T. Johnston (ed.), *The best of our owne: Letters of Archibald Pitcairne* (Edinburgh: Saorsa Books, 1979), p. 56.

In 1702, after Newton's resignation, Whiston was elected Lucasian professor at Cambridge with the help of Richard Bentley.[411] His candidature was strongly supported by Newton, who at the time saw in that promising mathematician a worthy successor and a dedicated disciple – Whiston, indeed, had already done Newton's teaching while he took up the reins as Master of the Mint. Whiston's lectures in Cambridge were clearly intended as a homage to Newton and his work. Messages of praise for his predecessor can be found throughout Whiston's lectures while their content closely followed Newton's ideas as established in the *Principia*. As for the style, Whiston did not adopt his master's alleged obscurity; instead, he designed his lectures "In Usum Juventutis Academicae" (For the use of young students in the University),[412] with the ultimate goal of rendering Newton's mathematical natural philosophy easier to digest. Whiston's pedagogical program can be recognized in the opening words of his *Praelectiones Astronomicae*:

> After having dispatch'd the Matters of pure Astronomy, we proceed unto the other Part of our Work, the Philosophy of the Famous Sir Isaac Newton. For we are purpos'd to trace the Steps of that Great Man, and to set forth his principal and most noble Philosophical Inventions in a more easy Method; that so we may bring that (as I may say) Divine Philosophy within the Reach and Comprehension of those, who are but indifferently perhaps exercis'd in the Mathematicks, and communicate the Knowledge thereof as far as may be.[413]

Whiston's attempt to promote the dissemination of his master's theories and to make them easier for the multitude involved not only the academic context but also more informal milieus, especially after 1710 when he was charged with heresy and deprived of his chair. In 1712, he published the broadsheet *Scheme of the solar system* illustrating the orbits of the comets as described by Edmund Halley and based upon Newton's physics.[414] As he reported in his memoirs, that "scheme has been of great reputation and advantage among the curious ever since".[415] During the 1710s Whiston was

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[411] Elected Master of Trinity in February 1700, Bentley was determined to improve the teaching of (Newtonian) mathematics and natural philosophy at the college.
[412] This expression became a recurrent motif of Whiston's publications. When he curated an edition of André Tacquet's *Euclid* (1703), he explained that he did it "for the Use of young Students in the University". W. Whiston, *Memoirs*, vol.1, p. 115.
[413] W. Whiston, *Sir Isaac Newton's Mathematick Philosophy More Easily Demonstrated* (London, 1716), p. 1.
[414] W. Whiston, *A scheme of the solar system, with the orbits of the planets and comets belonging thereto, described from Dr. Halley's accurate table of comets, Philosoph. Transact. No. 297 founded on Sir Isaac Newton's wonderful discoveries by William Whiston* (London, 1712).
[415] W. Whiston, *Memoirs*, vol.1, p. 191.

also very active in divulging Newton's theories in London coffeehouses, where he began lecturing in March 1713, and in Francis Hauksbee's instrument-making shop. Here the two entrepreneurs began an experimental lecture course mainly devoted to Newton's physics – though with an easier approach – and with the replication of his experiments.

Did Newton agree with such uncurbed dissemination of his scientific theories? The answer to this question is twofold. On the one hand, the English mathematician initially supported Whiston and approved the publication of textbooks like the *New Theory*. In his memoirs, Whiston recalled that in May 1695 he had discussed his work with Newton who, after reading the draft, sent it back to the author with his comments and corrections. Likewise, Newton presumably endorsed the mention of his theories in Whiston's mathematical lectures at Cambridge – a position that Newton himself had helped to achieve. On the other hand, Newton never encouraged Whiston's public revelation of his theological creed, especially concerning his antitrinitarian belief. In his publications, he was always very cautious about his unorthodox views. When he published the "General Scholium" to the second edition of the *Principia*, for example, he revealed some aspects of his most esoteric thoughts, though in a veiled and dissimulated manner; only those most astute readers and his closest interlocutors could find his heretical private beliefs among the lines of his text and discern its meaning.[416] Whiston certainly was among these few people: as soon as he recognized the antitrinitarian nature of some propositions of Newton's General Scholium, he began to translate some theological passages that he eventually appended to his antitrinitarian work *Three Essays* (1713). With that publication, Whiston was associating Newton's theological view with the antitrinitarian creed.[417]

The public exposure of Newton's theological thoughts fatally compromised the relationship between master and disciple. From the 1710s Newton increasingly distanced his name and his work

[416] L. Stewart, "Seeing through the Scholium: Religion and Reading Newton in the Eighteenth Century", *History of Science*, 34(2), pp. 123–165.
[417] The full title of Whiston's 1713 work was: *Three Essays, I. The Council of Nice Vindicated from The Athanasian Heresy II. A Collection of Ancient Monuments relating to The Trinity and incarnation, and to the History of the Fourth Century of the Church. III. The Liturgy of the Church of England Reduc'd Nearer to a Primitive Standard.*

from Whiston who, nevertheless, continued to praise his erstwhile master and to popularize his work both in public and private.[418] After Newton's death, Whiston blamed his master – and his "fearful, cautious, and suspicious temper" – for the rupture of their relationship.[419] The real cause of their estrangement, however, resided in the fact that in the 1710s Whiston had become a wild card that Newton could neither control nor handle. It is important to note that Whiston and Newton had always had opposite policies in terms of publication, and they could not find a common ground to smooth their differences. In this sense, their relationship represents a very interesting case of a master-disciple relationship born in the name of the Pythagorean behavioural rules. As a new Pythagoras, Newton disclosed the core of his theories only within a circumscribed circle of trusted friends and disciples, who were then employed for targeted and controlled dissemination of his works. As a new Hippasus – the insubordinate disciple of Pythagoras who revealed the mathematical teachings of his master to the uninitiated – Whiston was more inclined to adopt an amorphous divulgation of Newton's theories, with the ultimate goal of rendering them easier for a lay readership.[420]

Newton was not completely uninterested in disseminating his natural philosophy, but he wanted to follow a controlled strategy to spread his works, relying on men that would act under his disposition. In this sense, the edition of the Latin version of his *Opticks* in 1706 was the result of a synergic and successful collaboration between his disciples Samuel Clarke and Abraham De Moivre: the former translated Newton's English text into Latin while the latter reviewed the translation and managed the print operation.[421] Clarke had already proved his loyal adherence to the program of dissemination of Newtonianism when in 1697 he had published a Latin translation of Rohault's *Traité de physique*, a text mainly based on Descartes' physics which Clarke annotated

[418] In 1717, for example, Whiston dedicated his *Astronomical Principles of Religion, Natural and Reveal'd* "To the Illustrious Sir Isaac Newton".
[419] W. Whiston, *Memoirs of the life and writings of Mr. William Whiston* (London, 1753), 2nd ed., vol.1, pp. 250-51.
[420] C. H. Kahn, *Pythagoras and the Pythagoreans: A Brief History*, (Hackett Publishing Company, 2001).
[421] R. Westfall, *Never at Rest,* p. 648.

with references to the theories of Newton.[422] In 1702 and 1710 Clarke produced two further editions of that work, with the Newtonian footnotes increasingly eclipsing the Cartesian content. Eventually, the disciple's work resulted in expanding the reach of Newton's natural philosophy and later editions of Clarke's Rohault became standard textbooks in the study of physics in England.

The intellectual shift operated by Clarke in his version of Rohault's work did not remain unnoticed; among others, William Whiston remarked that Clarke had made Newton's system easy enough for the understanding of ordinary mathematicians; persisting with the use of "Cartesian fictitious Hypotheses" would be like continuing to eat "old Acorns, after the Discovery of new Wheat, for the Food of Mankind".[423] Whiston highly appreciated Clarke for his mathematical ability and recognized in him a true disciple of Newton. In recalling his first meeting with that young mathematician – in 1697 Clarke was only twenty-two-year-old, Whiston revealed his admiration for him, who knew "so much of those sublime Discoveries, which were then taken almost a Secret to all, but to a few Mathematicians". Clarke's closeness to Newton was undeniable; the disciple, indeed, continued to support publicly Newton and his cause. During the 1710s, his efforts to promote the Newtonian system were canalized into the channel of theology and philosophy. The notorious correspondence that he exchanged with Leibniz through the mediation of Caroline, Princess of Wales, provides interesting elements to explore further aspects of Newton's discipleship.

The popularization of Newton's natural theology and philosophy

When Newton published his works on natural philosophy, he gave expression not only to his scientific achievements but also to their underlying philosophical principles. The Newtonian system – understood as the core conceptual and metaphysical principles underpinning his natural philosophy – elicited various reactions at different levels and from different kinds of intellectuals.

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[422] M. Dobre, "Rohault's *Traité De Physique* and its Newtonian Reception", in A. Roca-Rosell (ed.), *The Circulation of Science and Technology: Proceedings of the 4th International Conference of the ESHS, Barcelona, 18-20 November 2010* (Barcelona: SCHCT-IEC, 2012), pp. 389-394.
[423] In W. Whiston, *Historical memoirs of the life of Dr. Samuel Clarke* (London, 1730), pp. 5-7.

Among them, the German polymath Gottfried Leibniz in his private correspondence with Princess Caroline expressed his great concern about the declining status of "philosophy or rather natural theology" among English scholars, referring specifically to John Locke and Isaac Newton's views. Leibniz's words were given serious consideration by Caroline, who selected an excerpt from that letter and sent it to Samuel Clarke, triggering off a vibrant discussion on themes like the nature of space and time, the notion of miracle, and the cause of gravity.[424] The correspondence between Clarke and Leibniz began in 1715 and consisted of ten letters, five on each side.

Why did Caroline send Leibniz's polemic excerpt to Samuel Clarke? From the exchange between the Princess and the German philosopher preceding the dispute, we can see that the name of Clarke comes out from a conversation concerning the projected translation of Leibniz's *Theodicy*, a task that, according to the Bishop of Lincoln William Wake, no one would be able to realize but Clarke.[425] As Caroline remarked to Leibniz, however, Clarke was "too opposed to your opinion to do so; he would certainly be the most suitable person of all; but he is too much of Sir Isaac Newton's opinion and I am myself engaged in a dispute with him".[426] From this letter dated 26th November 1715, it emerges that Clarke was considered a clear and evident disciple of Newton. And in fact, Caroline continued: "I implore your help; he [sc. Clarke] guilds the pill and is not willing to admit that Mr. Newton has the opinion that you ascribe to him. But you will see from the enclosed paper that it comes to the same thing". Sending the provocative excerpt to Clarke meant engaging Newton himself. The master, indeed, would not let his disciple reply to theological questions concerning his own works without participating first-hand in the dispute.

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[424] On this controversy see: D. Bertoloni Meli, "Caroline, Leibniz, and Clarke," *Journal of the History of Ideas*, 60 (1999), pp. 469–86. R. Ariew (ed.), *G. W. Leibniz and Samuel Clarke. Correspondence* (Indianapolis, 2000). A. Koyré, I. B. Cohen, "The Case of the Missing Tanquam: Leibniz, Newton & Clarke", *Isis*, Vol. 52, No. 4 (Dec., 1961), pp. 555-566.
[425] H.G. Alexander (ed.), *The Leibniz-Clarke correspondence, together with extracts from Newton's Principia and Opticks* (New York: Philosophical Library, 1956), p. 190.
[426] *Ibid.*

There is scarce evidence of Newton's direct intervention in the drafts of Clarke's letters, a fact that can be explained both by their regular personal meetings and also by their mutual skill in hiding their true opinions from wider view. Nevertheless, several hints lead to the conclusion that Newton was involved behind the scenes of the controversy. The only document in his handwriting consists of a copy of Leibniz's "Apostille" to his fourth letter on atoms and the void, where Newton wrote the note "received of the Princess May 7th 1716, and copied May 8".[427] In addition to this document, from the diary of Mary Cowper, Lady of the Bedchamber to Caroline, we learn that on 11th February 1716 "Sir Isaac Newton and Dr Samuel Clarke came this afternoon to explain Sir Isaac's System of Philosophy to the Princess" – meaning that master and disciple were both personally and actively involved in defending their position in the controversy. Besides, the Princess herself was convinced that Clarke's letters were "not written without the advice of Chev. Newton."[428]

As we have seen, the fact that a disciple fought on behalf of his master was neither singular nor peculiar in the context of 17th-century controversies on natural philosophy. In the 1610s, for example, Benedetto Castelli was directly involved in a dispute between Galileo and his peripatetic interlocutors on the theme of floating bodies. On that occasion, the disciple was allowed to publish harsh replies to his opposers, though most of the texts were written by Galileo himself. Similarly, in 1613, Castelli participated as Galileo's wingman in a controversy concerning the literal interpretation of the Holy scriptures. Like the Clarke-Leibniz dispute, even this discussion involved a high-ranking female patron, the Grand Duchess Christina of Lorraine, who mediated the conversation between Castelli and his – and Galileo's – opposers. Eventually, the dispute became for Galileo a good occasion not only to confront his rivals but also to expose and circulate his ideas on that topic through the well-known *Letter to Benedetto Castelli* and *Letter to Christine of Loraine*. Similarly, in 1717 Clarke published his exchange with Leibniz,

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[427] D. Bertoloni Meli, "Newton and the Leibniz–Clarke correspondence", in R. Iliffe, G. E. Smith (eds.), *The Cambridge Companion to Newton* (Cambridge, 2016), pp. 586-96.
[428] H. G. Alexander (ed.), *The Leibniz-Clarke correspondence,* p. 193.

thereby enabling its circulation so that Newton's philosophical and theological views could reach a wider readership in a not excessively technical style.

In the context of the dispute, Clarke and Newton's names were often associated by their interlocuters, as to stress the fact that they believed in the same principles, fought for the same ideals, and belonged to the same "sect". In his letter to Caroline, Leibniz referred to "Monsieur Newton, et ses sectateurs", an expression that defines well how Leibniz saw Newton's circle – a secretive, organized body led by a master and joined by devoted sectarians that supported the master's cause and fought against his enemies. That controversy, indeed, was not only an intellectual confrontation on theological and philosophical issues; it also represented an attempt to reciprocally undermine the authority of the contender, the credibility of his worldviews, and the consensus that he had created through his acolytes.

The controversy with Leibniz was not the only episode that Newton capitalized on to disseminate his theological and philosophical views. The friendly correspondence that he exchanged with Richard Bentley between 1692 and 1693 represented another important means to give resonance to those aspects of the *Principia* that the author himself would neither publish nor disseminate within an amorphous readership.[429] The occasion for initiating the exchange occurred in 1692 when Bentley was asked to deliver the inaugural series of the Boyle Lectures, consisting of eight discourses on the evidence of Christianity. At first, Bentley tried to conceive by himself the content of his sermons; however, he soon realized that a satisfactory confutation of atheism – the topic that he chose for the first lectureship – required demonstrations in natural theology that were grounded in the new mathematical natural philosophy. Corresponding with Newton would be of great help in discussing such topics. On the other hand, Newton clearly prized that opportunity: Bentley could be the indirect amplifier of the religious significance of his natural philosophy.

[429] I. B. Cohen, R. E. Schofield, *Isaac Newton's papers & letters on natural philosophy and related documents* (Harvard University Press, 1958), pp. 271-394. A. Koyré, *Newtonian Studies* (Chapman & Hall, London, 1965), pp. 201-220.

The exchange between Newton and Bentley consisted of eight letters, four on each side, discussing a huge variety of topics that included the nature of gravity, the formation of the solar system, the concept of action-at-a-distance, and the role of God in the world.[430] Newton's letters were of great value to Bentley's purpose; as Koyré remarked, the English theologian "follows so closely, and even so servilely, Newton's teaching, or lessons – he copied nearly verbatim the letters he received from him, adding, of course, some references to the Scriptures and a good deal of rhetoric that the views he expresses can be considered as representing, in a large measure, those of Newton himself."[431] Thus, Bentley's sermons represented a precious window on Newton's intellectual world, but also a successful prototype of its divulgation.

From this perspective, Bentley might be considered as one of Newton's disciples; but did he have those essential traits to be one of them? Like Clarke, Bentley was a good theologian, but he was neither a natural philosopher nor a mathematician. Unlike the former, however, the latter couldn't master the technicalities of Newton's works. When he approached the *Principia* for the first time, Bentley realized that the text was out of his league and that he was not skilled enough to grasp its contents. He needed help and guidance. Initially, he wrote to John Craig asking advice about preliminary readings that would enable him to understand Newton's work. The list that Craig sent back to his correspondent, however, was too long and still not practicable for a beginner. It was only when Bentley appealed directly to Newton that he received a reasonable list of "books to be read before endeavouring to read and understand the *Principia*". Newton also suggested Bentley to deal only with several targeted passages of his work without deepening its scientific technicalities. Eventually, the English theologian followed closely Newton's suggestion and grasped the general sense of the work; his understanding, however, was very limited to those parts of the text that did not require a solid mathematical background.

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[430] H. Guerlac, M. C. Jacob, Bentley, "Newton, and Providence: The Boyle Lectures Once More", *Journal of the History of Ideas*, 1969, Vol. 30, No. 3, pp. 307-318.
[431] A. Koyré, *From the Closed World to the Infinite Universe* (The Johns Hopkins Press: Baltimore, 1957), p. 179.

Bentley's case represents a fascinating example to understand all the nuances of Newton's discipleship. Although he cannot be considered a disciple of Newton in a narrow sense – he was mathematically less adept than any other would-be acolyte – he was nonetheless an important ally, a valid interlocutor and ultimately a good friend. In the years following the exchange on natural theology, indeed, Bentley and Newton maintained a close and friendly relationship. The election of the former as Master of Trinity College in 1700 strengthened their alliance: in 1702, Bentley supported the election of William Whiston as Newton's successor in Cambridge while a few years later he endorsed the establishment of the Newtonian system by persuading Newton to edit the second edition of his *Principia* at the Cambridge University Press.

When he was appointed Lucasian Professor of Mathematics in 1669, Newton dutifully fulfilled his pedagogical obligations. His lectures and early publications on mathematics attest his commitment to the teaching of young students and give a glimpse of the exceptional rise that followed. The publication of the *Principia* represented a turning point: the text presented many difficulties even to the most skilled scholars of the time, but it was nonetheless recognized by many as a great work. It was in the aftermath of that publication that Newton's inner circle began to flourish. On the one hand, the *Principia* acted as a gravitational attractor for ambitious young men ready to throw themselves at its author and to act as formal – or informal – interpreters of his works. On the other hand, Newton began to understand the need of being surrounded by skilled mathematicians and natural philosophers to establish the credibility of his abstruse and counter-intuitive idea of universal gravitation.

When they first approached the master, the would-be disciples were prepared to leverage their skills to get closer to Newton and benefit from his aura. Then, they had to go through various trials and tribulations before they could be said to be part of Newton's inner circle: some of them had to prove their loyalty to the master and to his system of the world; others, were tested on their technical skills and abilities. Eventually, each acolyte established with Newton a mutually beneficial relationship: the former could have a privileged access to his mind and, therefore, to the

true meaning of his texts; the latter could rely on trusted allies that endorsed and promoted every aspect of his project. The acolytes, indeed, proved to be prepared to champion Newton's works on natural philosophy, but they were also well equipped to defend other areas like theology and philosophy. When the priority dispute with Leibniz broke out, the role of discipleship became even more crucial; the acolytes were then called to defend the master's theories and to fight his intellectual war.

CHAPTER 6

DISCIPLES AT WAR.

THE ROLE OF DISCIPLESHIP IN THE PRIORITY DISPUTE BETWEEN LEIBNIZ AND NEWTON

Discipleship: a bridge between the private and the public dimension of mathematics

When he was elected Lucasian professor in 1669, Newton had already achieved brilliant results in mathematics. In October 1666 he had collected his discoveries on the calculus of fluxions in a small tract and in the summer of 1669, shortly before he was appointed as the second Lucasian professor, he had written *De Analysi*. After the election to the Lucasian chair, he composed his work on series and fluxions, *De Methodis,* and during the next two decades, he produced his lectures on algebra, which he deposited in the University Library in 1684. In the following years, Newton refined and expanded his mathematical findings but none of his full works was either published in print or disseminated through academies and journals before the 1700s.[432]

Historians have typically ascribed Newton's reluctance toward the wider dissemination of his work to his character – he was notably sensitive to criticism and reluctant to any involvement in quarrels – but also to the social contexts in which he was living. As Niccolò Guicciardini points out, moreover, the nature of Newton's mathematical work did not fit the emerging channels of communication of the time: being more an array of techniques rather than a theory, the new analysis was more suitable for oral communication or correspondence rather than printed books.[433] These explanations help to understand Newton's unforthcoming attitude and contribute to explaining why, from the 1670s, he began to circulate part of his mathematical works within a restricted circle of mathematicians. He wished to keep his papers private; this approach, however, conflicted with the increasingly public dimension of science and with the need to assert priority over his discoveries.

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[432] I. Newton, *The Mathematical Papers of Isaac Newton: Vol. 1 1664-1666* (New York, Cambridge UP, 1967; repr. Cambridge UP, 2008), ed. D.T. Whiteside.
[433] N. Guicciardini, *Isaac Newton on Mathematical certainty and method* (MIT press, 2009), pp. 345-6.

For almost three decades Newton's idiosyncratic version of scribal publication allowed him to balance the relationship between the private and the public dimension of his mathematical work.

Establishing the nature of Newton's network of scientific and mathematical allies from the 1670s to the 1690s is a difficult task. Even among his private correspondents, indeed, Newton did not circulate his findings indiscriminately: some mathematicians like John Collins received Newton's results on series, algebra, and the organic description of curves; others like Edmond Halley were allowed to see – and transcribe – Newton's *De Quadratura*. Before 1694, it seems that almost none of Newton's interlocutors was allowed to know about the direct and inverse method of fluxions as developed in *De Methodis*. Only on a few occasions did Newton refer to a "general method" with his correspondents, although he did not disclose its foundations. The two letters that he sent to Leibniz in the 1670s represent the most emblematic case of this kind.

Composed in June and October 1676 respectively, the *epistola prior* and the *epistola posterior* constitute a significant example of Newton's controlled circulation of his mathematical achievements. In those letters, the Lucasian professor released a carefully managed repertoire of his mathematical findings without nevertheless revealing the demonstrations or fundamental method required to achieve them. Although he was prepared to reveal significant results in these missives, the fact that he concealed the core of his achievement behind an anagram shows that part of his motivation in writing these texts was that he wanted to secure the priority of his discoveries over other mathematicians – a plan that, as we know, did not work.[434] Far from being only a heuristic technique, indeed, Newton designed his new analysis to serve a higher purpose than other algebraic methods and, for this reason, he believed it to be not indiscriminately "worthy of public utterance".[435]

[434] As Niccolò Guicciardini points out, Newton did not conceive the anagrams to hide his mathematical theorems but rather to assert the priority of his discovery. See N. Guicciardini, *Isaac Newton on Mathematical certainty and method,* pp. 358-359.
[435] *NC*, vol. 3, p. 279.

The exchange with Leibniz helps to understand the main features of Newton's strategy for disseminating his mathematical writings in the 1670s; likewise, it is useful to inquire into the Leibniz's strategy for disseminating his mathematical work, which, by virtue of appearing in print, was aimed at a much broader – thought still learned – audience. During the 1670s, 80s and 90s, Leibniz – who had a very different view of the function and operation of the Republic of Letters than Newton did – was committed to circulating his mathematical work within the learned community. For this purpose, he resorted to every means at his disposal: academies, journals, printing publications represented essential mechanisms for spreading his ideas across the Continent. On the other hand, the novel character, technical difficulty, and printing errors present in publishing the new calculus made Leibniz's work inaccessible to most mathematicians of the time. For example, in August 1690, Christiaan Huygens lamented the obscurity of the new algebraic calculus to Leibniz.[436] A few months later, the Dutch mathematician had finally "reconnu les fondements de ce calcul et de toute vostre methode, que j'estime estre tres bonne et tres utile",[437] but in 1693 he was still unfamiliar with certain expressions like "ddx" and asked Leibniz for further instructions.[438]

The difficulties that even accomplished practitioners like Huygens met in understanding the new calculus speak loudly about the process of learning a new mathematical technique without a proper guide. A mediation between the author and its audience was needed. One solution to this problem emerged between the end of the 1680s and the beginning of the 1690s when Leibniz entered into contact with the Swiss brothers Jakob and Johann Bernoulli. The two brilliant mathematicians soon turned out to be powerful allies: not only did they contribute to developing, extending, and establishing Leibniz's *nova methodus*, but they also promoted a systematic education of his readership and dissemination of his work.

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[436] "J'ay vu de temps en temps quelque chose de Vostre nouveau calcul Algebraique dans les Actes de Leipsich, mais y trouvant de l'obscuritè, je ne l'ay pas assez etudiè pour l'entendre." Huygens to Leibniz (24th August 1690), *Leibnizens Mathematische Schriften*, II, p. 44.
[437] Huygens a Leibniz (9th October 1690), *Leibnizens Mathematische Schriften,* II, p. 46.
[438] "M'y voilà maintenant mediocrement versé, si non que je n'entens encore rien aux *ddx*, et je voudrois bien scavoir si vous avez rencontré des problemes importants ou il faille les emploier, afin que cela me donne envie de les etudier." Huygens to Leibniz (17th September 1693), *Leibnizens Mathematische Schriften,* II, p. 160.

The first approach between Leibniz and Jakob Bernoulli – the elder of the two brothers – happened on 15th December 1687, when the latter addressed the former to ask for further explanation about his algorithm of differential calculus. Finding Leibniz's work tantalising but unnecessarily opaque, Jakob's letter was a request for clarification, and he revealed significant information about the reasons for writing to Leibniz.[439]. Jakob explained that he did not want to be counted "among the number of those who try – because they have no other means – to raise their fame by approaching great men. For if this insanity is strange to someone, then it must certainly be most strange to me, who would rather stay unknown, particularly to You, than making myself known. Therefore" continued Jakob "I want you to be convinced, Worthy Sir, that nothing else has driven me to write to you than the ardour by which I glow for matters mathematical, and an insatiable desire to make progress in these."[440] Jakob's words highlight an important aspect concerning the beginning of a master-disciple relationship. Being associated with the name and the authority of an increasingly renowned mathematician constituted a powerful reason for young students to address a master. Jakob, instead, revealed to Leibniz his noble intention to become closer to him only for the sake of mathematics and its advancement. His letter nonetheless ended with a solemn promise:

> If you judge me worthy of sharing in a ray of light of this method of yours (which I ardently desire), as far as your very important occupations will allow you, you will ensure that, once I have become aware of your discoveries, I will become not only an admirer of them, but also a worthy estimator and promoter.[441]

With these words, Jakob offered himself at the service of Leibniz and of his mathematical work.

Leibniz did not immediately reply to Jakob's letter – at the time he was travelling and could not receive it. Moreover, his answer arrived in Basel – where Jakob had obtained the mathematics chair in 1687 – only in 1690. This delay gave the Bernoulli brothers enough time to delve further

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[439] The full title of Leibniz's paper was *Nova methodus pro maximis et minimis, itemque tangentibus, quae nec fractas nec irrationales quantitates moratur, et singulare pro illis calculi genus*.
[440] Jakob Bernoulli to Leibniz (15th December 1687) in C. I. Gerhardt, *Leibnizens mathematische Schriften*, III, p. 10.
[441] "Hujus vestrae methodi si aliqualem (quod impense flagito) impertiri mihi digneris radium, quantum per gravissima Tua negotia licebit, eo ipso facies, ut deinceps non nudus Tuorum Inventorum admirator, sed et dignus eorum aestimator ac praeco futurus sim". C. I. Gerhardt, *Leibnizens mathematische Schriften*, III, p. 13.

into Leibniz's calculus, to unravel its obscurity, and "learn the whole secret". Besides the private correspondence, Jakob and Johann proved their outstanding ability by providing solutions to the thorny problems that mathematicians like Leibniz posed to the scholarly community to demonstrate that the new calculus could be applied successfully to problems in mechanics. For example, in May 1690, by using the differential calculus, Jakob found a solution to the problem of the *curva aequabilis descensus* (or isochronic curve) that Leibniz had posed in the *Nouvelles de la République des Lettres* in September 1687, while in 1691 Johann published his answer to the problem of the catenary curve in the *Acta Eruditorum* by reducing the problem to the rectification of a parabola.[442] Those brilliant achievements contributed to placing the two brothers among the most prominent mathematicians of the Continent and presumably induced Leibniz to establish with them a closer relationship.

It is extraordinary that during his lifetime, Leibniz never met either Jakob or Johann Bernoulli. Notwithstanding the technical character of their exchange, he established with both a robust correspondence that lasted until his death in 1716. This fact tells something about the way in which the German philosopher cultivated allegiance by means of the Republic of Letters and highlights the importance that this agency played for him throughout his life: Leibniz's correspondence counts roughly 20000 surviving letters, which he exchanged with more than 1300 correspondents.[443] At first the Bernoullis acted as a team, and when he wrote his first letter to Leibniz, Jakob was still tutoring his younger brother. However, by 1690, Johann's talent had blossomed and the friction with his brother became increasingly unbearable; it was time for him to find his own path. From the mid-1690s, the two brothers maintained a regular and independent

[442] S. Alassi, "Jakob Bernoulli's analyses of the Funicularia problem"*, British Journal for the History of Mathematics*, 35:2, pp. 137-161.
[443] H. Hotson, "Leibniz's Network", in M. R. Antognazza (ed.), *The Oxford Handbook of Leibniz* (Oxford, 2018), pp. 563-90.

correspondence with the German philosopher, although they kept working with the same goals: extending Leibniz's new method, creating his readership, and spreading his work.[444]

The Bernoulli brothers had a major impact on the development of Leibniz's techniques. They explored the variety of applications that the calculus allowed, demonstrating the generality and versatility of the new mathematical tools rather than their logical foundations. Leibniz highly appreciated their contributions and endorsed their activities. Indeed, although the metaphysics underlying his indivisibles was consonant with his more general ontology, the German mathematician intended to promote the practical use of his algorithm without necessarily stressing the philosophical values underpinning his method. This aspect contrasts with Newton's approach, which was more inclined to establish rigorously the principles of his mathematical discovery and aimed at transmitting such values to a more circumscribed readership. Consequently, the two mathematicians established different kinds of relationship with their disciples: Leibniz selected his acolytes for their technical abilities and expected them to facilitate the circulation of his method within a broader readership and in journals. Newton, on the other hand, established close relationships with a few talented mathematicians who, once turned into devoted and trusted disciples, evangelized their master's mathematical and philosophical views within a still restricted circle of people.

The different strategies that the two mathematicians devised at the beginning of the 18th century to disseminate their mathematical achievements reflect the different role that their disciples played within the intellectual community of the time. By 1704, the reception of both Newton and Leibniz's calculus remained very limited – almost no one in Continental Europe knew about Newton's method of fluxions and very few people were familiar with Leibniz's integral calculus; nevertheless, the Bernoullis were much further advanced than English and Scottish mathematicians, and crucially, their work was published and could more easily be built upon. In a few years, indeed,

[444] On the relationship between Jakob and Johann Bernoulli see J. Peiffer, "Jakob Bernoulli, teacher and rival of his brother Johann", *Electronic Journal for History of Probability and Statistics*, vol. 2/1b, June 2006.

Leibniz's calculus became increasingly popular and firmly established within a wider circle of intellectuals. Its enthusiastic reception was mainly due to the capillary dissemination operated by Johann Bernoulli, while by now his brother Jakob had a marginal role. The former, indeed, often bewailed the latter's tendency to keep his mathematical discoveries secret. In a letter to Montmort dated 1719, in recalling the origin of the differential and integral calculus, Johann wrote:

> You naively admit that I and Mr. Leibniz have revealed early on to the marquis de l'Hôpital our secrets, which, as you have added, would have remained secret to all mathematicians until this day, if we had wanted to hide them as Mr. Newton did; who knows what would have happened, had I followed my brother's bizarre moods, he who was initially as secretive as Mr. Newton. I can show you some of the letters that he has written me, in which he complained about the fact that I so willingly shared our secrets and exhorted me to hide them.[445]

Johann's actions in promoting the understanding and development of the Leibnizian calculus were not only limited to the circulation of Leibniz's work but also to the creation – and education – of his readership. Besides being a brilliant mathematician, indeed, Bernoulli was also a capable and active teacher. The results that he obtained all over the Continent during the 1690s testify to the effectiveness of his systematic program: by the end of the century, Leibniz's calculus and its notation were becoming increasingly distributed within the most important intellectual milieus. Johann's ability attracted pupils from Germany, Switzerland, Holland, and England; it was in Paris, however, that his work exerted the greatest influence. There, the presence of circles of savants favoured the circulation of new discoveries and the establishment of a strong network of intellectuals. Headed by the neo-cartesian Nicolas Malebranche, mathematicians such as Louis Byzance, Charles René Reyneau, Pierre Rémond de Monmort, and Pierre Varignon received their first introduction to Leibniz's calculus from Bernoulli.[446]

The case of the Marquis De L'Hôpital was the most emblematic of this kind. After meeting Bernoulli in the salon of Malebranche, the Marquis engaged the Swiss mathematician to be his personal tutor on the new calculus. At first, the two agreed on four lessons per week in Paris; after

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[445] Bernoulli to Monmort (15th June 1719), http://dhlab.unibas.ch/beol/
[446] See a letter from Leibniz to Bernoulli dated 7th June 1694, in https://ark.dasch.swiss/ark:/72163/1/0801/O_HTJJyoTPmyakle3hWP6gP.20191028T110449832Z

six months, they moved to L'Hôpital's chateau. When Bernoulli left Paris, the mathematical lessons continued via correspondence. Eventually, this dense pedagogical process resulted in the publication of L'Hôpital's *Analyse des Infiniment Petits pour l'Intelligence des Lignes Courbes*, the first published book on Leibniz's differential calculus. L'Hôpital's textbook was published anonymously in 1696 and presented brilliantly most of the contents of the course on differential and integral calculus that Bernoulli had delivered to his pupil in France. Regardless of the controversial authorship of the book – in letters to Leibniz, Varignon, and others Bernoulli often complained that most of what was attributed to l'Hôpital belonged to himself – [447] it is important to highlight the successful results of Johann's commitment to the dissemination of the calculus in books and articles: L'Hôpital's book went through several editions and remained a standard textbook for almost a century.

The strategy of dissemination promoted by Leibniz during the 1690s heavily relied on the support of brilliant mathematicians like Johann Bernoulli. The nature of his mathematical discoveries allowed him to establish with his right-hand men a long-distance relationship that favoured the rapid circulation of his work and its development. The organized structure that Johann devised to popularize the new calculus was effective and productive and contributed to establishing Leibniz's calculus and its notation. In a few years, a consistent group of mathematicians over the Continent mastered, extended, and developed the results that the German philosopher had achieved in the previous decades even more spaciously than Leibniz himself. By the end of the century, the calculus was becoming widely taught in the most prestigious universities from north Italy to Holland. A new challenge, however, was awaiting across the channel. Newton and Leibniz were going to begin one of the harshest quarrels in the history of mathematics: the priority dispute over the discovery of the infinitesimal calculus.

[447] C. Truesdell, "The New Bernoulli Edition", *Isis*, Mar., 1958, Vol. 49, No. 1 (Mar., 1958), pp. 54-62.

Wind of war

During the 1690s, Leibniz's calculus was slowly emerging on the Continent. The large-scale dissemination operated by his disciples not only established a new mathematical method but opened to a huge variety of applications in the fields of mechanics and natural philosophy that broadened the extent and significance of the German philosopher's achievement. On the other hand, at the beginning of the decade, the English counterpart was barely known even within the British milieu. The first printed appearance of Newton's ideas of fluxions came to light only in 1693, when John Wallis briefly outlined the terminology and notation of Newton's method in Volume II of his *Opera Mathematica*. A staunch promoter of English mathematicians, Wallis was eager to spread Newton's achievements; in the Preface to Volume I – published in 1695 – of his work, he stated:

> Here [sc. in Volume II, that is in the Latin *Algebra*] is set out Newton's method of fluxions, to give it his name, which is of a similar nature with the differential calculus of Leibniz, to use his name for it, as anyone comparing the two methods will observe well enough though they employ different notations.[448]

At the time, Wallis had no intention of hinting at any competition between the two mathematicians – indeed, he considered the two methods to be equivalent. His prime concern was rather to encourage Newton to publish his own method. The absence of any grudge between Leibniz and Newton during the first half of the 1690s can be also discerned in the friendly tone that characterized the two mathematicians' respective statements. In a letter to Newton dated 1693, Leibniz appeared genuinely cordial with his interlocutor – an attitude that was even emphasized in several missives that the German philosopher sent to his friends to whom Newton was always mentioned with great respect. Similarly, the Lucasian professor publicly referred to Leibniz in a friendly tone. A thorough analysis of the intercourse between Newton and his first disciples, however, might reveal the first signals of a strain that eventually culminated in the notorious dispute.

As we saw in the previous chapter, the first two disciples that entered Newton's orbit during the 1690s were Fatio de Duillier and David Gregory. At the time, the two mathematicians were

[448] J. Wallis, *Opera Mathematica*, Vol. I (1695).

among the very few people to have access to Newton's mathematical writings and became the first to support the establishment of his method. The documents that they produced in that period – correspondence, treatises, memoranda – represent a crucial source for understanding their adherence to Newton's mathematics and to grasp the instructions that the master had presumably imparted to them. Gregory's memoranda constitute the starting point of this analysis; their systematic and methodical composition, indeed, provides precious information on Newton's work on mathematics during the last decade of the 17th century.

From a memorandum dated 7th September 1694 it is possible to infer that, on the occasion of their earlier May meeting at Cambridge, Newton had disclosed to Gregory part of his still unpublished mathematical treatise *De methodis serierum et fluxionum.*[449] Gregory's account of the encounter not only attests to his knowledge of Newton's mathematical achievements but demonstrates that master and disciple had devised a plan to circulate part of those results. Particularly interesting is a draft of eleven points in which Gregory listed themes and authors to discuss in a mathematical treatise, with the purpose of illustrating Newton's method of fluxions more fully. Gregory's composition of the tract *Methodus Fluxionum,* which followed accurately the plan drafted in early September, corroborates this hypothesis.[450]It is hard to believe that Newton's role in managing the production and circulation of this text was marginal, and if Gregory had circulated the *Methodus Fluxionum* without his master's approval, it would have been known.[451] The procedure that Gregory chose to spread his treatise, moreover, is perfectly in line with Newton's own *modus operandi*: the *Methodus Fluxionum* was never published by its author but circulated as a form of scribal publication within a very circumscribed group of mathematicians close to Newton.

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[449] D. T. Whiteside (ed.), *The mathematical papers of Isaac Newton* (Cambridge, 1967–1981), vol. 7, p. 197.
[450] N. Guicciardini, "David Gregory's Manuscript 'Isaaci Neutoni Methodus Fluxionum' (1694): a Study on the Early Publication of Newton's Discoveries on Calculus", *Notes and Records of the Royal Society of London*, 2021.
[451] See George Cheyne's case in P. Beeley, «'There are great alterations in the geometry of late'. The rise of Isaac Newton's early Scottish circle», *British Journal for the History of Mathematics*, 35:1, pp. 3-24.

The content of the treatise was not only focused on Newton's mathematical achievements; as Niccolò Guicciardini has recently shown, Gregory ably contextualized the method of fluxions within the framework of previous and contemporary mathematical works both in England and on the Continent. The Scottish mathematician stressed the centrality of Barrow's method of tangents, from which "all [sc. the methods] easily flow" (*omnes [methodi] facile fluunt*) but he recognized the importance of the contributions of other mathematicians like Tschirnhaus and Leibniz.[452] Although the *Methodus Fluxionum* appears as a work illustrating the general development of the calculus, the goal of its author was evidently the elucidation of Newton's achievement. In this sense, it should be noted that Gregory often stressed the equivalence between Newton and Leibniz's methods, which "slightly differ only by their name" (*tantum nomine tenus differant*). Why would the disciple emphasize such equivalence in a treatise that celebrated Newton's method of fluxions? To answer this question, we should consider that Gregory was comparing Newton's work to a great mathematical achievement that was becoming increasingly acknowledged – and praised – over the Continent. By claiming that Newton's achievement was at least as great as that of Leibniz's, Gregory was not diminishing the magnitude of his master's discovery but was doing the very opposite.

In his work, Gregory often compared the two methods and declared their equivalence. In a passage of *Propositio* 1, for example, he stated that "Leibniz's Differential Calculus and Newton's Method of Fluxions […] differ only by their name". Shortly after, however, he added:

> But because *Newton's Method of Fluxions was not only invented first*, since it was known to Newton from 1664, but [also] its easy demonstration was worked out by its Author, while the Differential Calculus (as Leibniz published it without a Demonstration) needs to be demonstrated, indeed Barrow and Tschirnaus's Method are included in the Demonstration of the Method of Fluxions.[453]

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[452] Gregory's reference to Barrow's "method of tangents" did not represent an attempt to belittle Newton. Barrow's prominent role in inspiring Newton and Leibniz, indeed, became the official narrative in the *Commercium Epistolicum*, the pamphlet drafted by Newton and circulated in 1713 by the Royal Society to end the quarrel against Leibniz.

[453] "Sed quoniam Newtoni Methodus Fluxionum, non tantum primo inventa fuit, utpote Newtono nota ab anno usque 1664, sed eius demonstratio facilis ab Auctore pertexta sit, et Calculo Differentiali demonstranda (cum quippe absque Demonstratione edidit Leibnitius) inserviat, immo Barrovii et Tschirnausii Methodus in Fluxionum Metodi Demonstratione contineantur" – emphasis added. Christ Church Library, University of Oxford, MS 131, f. 193r. See https://digital.bodleian.ox.ac.uk/objects/9f161887-ec8e-40fe-b417-c11e5845d91d/surfaces/e29e96f5-05ab-4846-8909-e1bbf79758a9/

In this passage, Gregory was not only asserting the priority of Newton's Method of Fluxions over Leibniz's Differential Calculus, but also the easiness of its demonstration; this had allegedly been provided by its author while Leibniz did not publish it yet.

A similar attitude can be discerned in *Propositio* 5: after illustrating Barrow's method of tangents, Gregory reasserted the equivalence between the methods of Leibniz and Newton – they both "applied their methods to the determination of maxima and minima", before adding, however, that Newton also did so to the measure of spaces encompassed by straight and curve lines.[454] An interesting remark follows in *Propositio* 6 in which, after having illustrated Leibniz's method with Newton's language, Gregory underlined the advantages of the latter for its conception of magnitudes as generated by motion. This concept, he claimed, was more suitable to be applied to "physical matters" than Leibniz's conception of magnitudes as constituted by infinitesimal components. In the same passage, Gregory also compared the two methods in relation to purely mathematical operations and reasserted that although both methods could be equally used, "it is nonetheless wiser to begin with Newton's Fluxions, which are easier and smoother".[455]

Gregory's general judgment in the *Methodus Fluxionum* was pro-Newtonian, as the wide use of Newton's notation of fluxions in it confirms. The Scottish mathematician's treatise was not intended as a direct charge against Leibniz – on the contrary, the latter was often praised for his achievements; but neither was his attitude wholly neutral. Gregory lauded Newton's method for being more demonstratively powerful, more general, and easier to use, and subtly hinted at the priority of Newton's discovery, which, crucially, he dated back to at least 1664. We cannot

[454] "Cum tamen Neutonus et Leibnitius suas Methodos ad qu libet maxima et minima determinanda adhibeant, Newtonus etiam ad Spatia Curvis et rectis comprehensa mensuranda ut in decursu patebit". Christ Church MS 131, ff. 194v-195r.

[455] "Iam Methodus Fluxionum, quam Calculus Differentialis, nomina sunt huic rei aptissima. Tamen Fluxiones magis arrident, generalius quippe [f. 195v] nomen. Nam ad Mathematica ad res Physicas applicanda feliciter nihil magis conducit quam Generatio figurarum per motum locale". Christ Church MS 131, f. 195r.

determine how much Newton biased Gregory's opinion, but we cannot ignore the fact that the disciple wrote his treatise only a few months after his meeting with Newton – maybe the two mathematicians discussed those themes together in Cambridge. In support of this hypothesis, we should also consider that in the same period, Fatio De Duillier, the other acolyte that joined Newton's circle at the beginning of the 1690s, expressed similar ideas on the topic.

In a letter dated 18th December 1691, Fatio informed Huygens about the alleged priority and superiority of Newton's method over Leibniz's, hinting also at the fact that the latter devised his method only after 1676 when he exchanged a few letters with Newton on that topic:

> It appears to me by all that I have as yet been able to see (in which I include papers written many years ago) that Mr Newton is without difficulty the first inventor of the differential calculus and that he knew it as well as Mr. Leibniz does now, or even more perfectly, before the latter had even the least idea of it, which as it appears did not come to him before the occasion when Mr. Newton wrote to him on this subject. See if you please page 153 of Mr. Newton's book. Therefore I cannot cease to wonder that Mr. Leibniz takes no notice of this in the Leipzig Acta.[456]

In a later missive, Fatio strongly reasserted the priority of Newton's discovery over Leibniz, exalting bluntly the superiority and the generality of the Method of Fluxions in comparison with Leibniz's differential calculus.[457] Contrary to Gregory's approach, Fatio's words were openly charged with a degree of hostility and anticipated the frictions that emerged shortly after between Leibniz and Newton. It is possible that both Fatio and Gregory incubated those thoughts on their own; but since they provided similar versions – they both stressed the priority and the superiority of one method over the other – it is not impossible that they discussed those themes with the master during their meetings. For Newton's part, whatever he thought about the chronological priority and benefits of the fluxional method in comparison with the differential calculus, he was beginning to realize the importance of large-scale dissemination of his work and was demanding loyalty from those only too willing to give it; the acquisition of proselytes represented the privileged agency by which he could

[456] *NC*, vol. 3, p. 187.
[457] *NC*, vol. 3, p. 193-4.

maintain authorial distance, obtain credibility, and communicate elite knowledge to a wider audience.

On the other side, Johann Bernoulli was developing a similar attitude of hostility towards Newton. In a letter to Leibniz dated 15th August 1696, he began to sow the seeds of doubts in the mind of his master by asserting that Newton's fluxional method – as expressed in Wallis's treatise – did not differ from the differential calculus in anything but its name. In one passage, Bernoulli openly stated: "I do not know whether or not Newton contrived his own method after having seen your calculus, especially as I see that you imparted your calculus to him before he had published his method".[458] Bernoulli's statement represented a veiled accusation of plagiarism that Leibniz, nevertheless, did not embrace. In his reply, indeed, the German philosopher was rather inclined to think that Newton already possessed "some remarkable knowledge at that time which, in his usual way, he has greatly polished up in the subsequent period".[459]

Disciples at war

The priority dispute is usually referred to as an intellectual war between two of the greatest mathematicians of the time; Newton and Leibniz, indeed, were the formal protagonists of most of the events that characterized the controversy. The dispute was nonetheless instigated by the provocative statements of their disciples, who acted either on their initiative or under their masters' instructions. Understanding the reasons that brought Newton and Leibniz to create opposite factions that battled on their behalf is a crucial step to acknowledging the nuances of the priority dispute. On the other hand, it is equally important to grasp the reasons that motivated the disciples to sacrifice their own independence to support the cause of their masters.

[458] Bernoulli to Leibniz (15th August 1696), in C. I. Gerhardt, *Leibnizens mathematische Schriften* (Berlin and Halle: A. Asher and H. W. Schmidt, 1849-63), vol. III, pp. 316-17.
[459] Leibniz to Bernoulli (23rd August 1696), in C. I. Gerhardt, *Leibnizens mathematische Schriften,* vol. III, p. 320.

The first public clashes that preluded the dispute between Leibniz and Newton arose in 1699 when Fatio published a work dealing with the brachistochrone – *Lineae Brevissimi Descensus Investigatio Geometrica* – in which he publicly charged the German philosopher of plagiarism:

> Yet I recognize that Newton was the first and by many years the most senior inventor of the calculus, being driven thereto by the factual evidence on this point; as to whether Leibniz, its second inventor, borrowed anything from him, I prefer to let those judge who have seen Newton's letters and other manuscript papers, not myself. Neither the silence of the more modest Newton nor the eager zeal of Leibniz in ubiquitously attributing the invention of this calculus to himself will impose on any who have perused those documents, which I myself have examined.[460]

It is interesting to note that following this statement, Fatio referred to Leibniz's tendency to create and rely on disciples, a statement that would later be developed by Newton. In this case, it is difficult to determine Newton's role in the formulation of the accusation against Leibniz and in the choice of publishing it. We may infer that Fatio's ideas were to some extent based on having seen Newton's mathematical papers and discussed them – and their similarity or otherwise to Leibniz's ideas -- with him.

In the aftermath of that publication, John Wallis, on behalf of the secretary of the Royal Society Hans Sloane, reassured the German philosopher that Fatio had received the imprimatur for his work only by trickery, thereby releasing the English institution – and Newton himself – from any formal involvement in the dispute.[461] The relation between Newton and Leibniz at the time was still outwardly friendly. The two mathematicians publicly acknowledged each other's merits and recognized the fact that, at the time of their first exchange, they had both already devised their respective methods. This tone, however, did not last much longer.

The event that contributed to the beginning of the dispute characterized Newton's strategy of publication. Two main reasons moved the English mathematician toward a wider circulation of his work. Firstly, the dissemination of his manuscripts was getting out of control. In 1703 the Scottish

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[460] F. De Duillier, *Nicolai Fatii Duillierii R.S.S. Linee brevissimi descensus investigatio geometrica duplex. Cui addita est investigatio geometrica solidi rotundi in quod minima fiat resistentia* (London, 1699), p. 18.
[461] See R. Hall, *Philosopher at war*, pp. 119- 128, in particular p. 121; N. Guicciardini *Isaac Newton on Mathematical Certainty and Method,* p. 335.

mathematician George Cheyne had published a brief treatise entitled *Fluxionum Methodus Inversa* (1703), in which he had exposed a systematic account of the fluxional calculus.[462] Newton, who strongly disapproved of the publication of that tract, responded by encouraging Abraham de Moivre to reply on his behalf with the pamphlet entitled *Animadversiones in D. Georgii Cheynaei Tractatum de Fluxionum Methodo Inversa* (1704).[463] Cheyne's work was sufficiently irritating to provoke a public response from Newton himself, now backed with the additional authority of his recent election as President of the Royal Society. In 1704, he included as appendices to his *Opticks* the tract *De quadratura curvarum* and the treatise *Enumeratio linearum tertii ordinis*, the first of which revealed his mastery of integration techniques and caused Leibnizians such as Johan Bernoulli substantial concern.[464]

Secondly, acolytes such as Fatio were increasingly provoking Newton to publicly assert the superiority and priority of his mathematical work, and to defend the notion of "attraction" from the charge of obscurity.[465] The publication of *De Quadratura*, in which Newton highlighted the fact that he hit upon the method of fluxions in the years 1665 and 1666, did indeed stimulate a response from Leibniz, and in 1705 the German philosopher anonymously reviewed Newton's tracts in the *Acta Eruditorum.* Leibniz generally wrote approvingly about Newton's work, without nevertheless missing the occasion to mention his name and achievements:

> Accordingly instead of the Leibnizian differences Mr Newton employs, and has always employed, *fluxions, which are almost the same as the increments of the fluents generated in the least equal portions of time*. He has made elegant use of these both in his *Principia Mathematica* and in other publications since, just as Honoré Fabri in his *Synopsis Geometrica* substituted the advance of movements for the method of Cavalieri.[466]

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[462] G. Cheyne, *Fluxionum methodus inversa sive quantitatum fluentium leges generaliores* (London, 1703). See N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method*, p. 366.
[463] A. De Moivre, *Animadversiones in D. Georgii Cheynaei tractatum de fluxionum methodo inversa* (London, E. Midwinter, D. Midwinter, and T. Leigh, 1704)**.** For Bernoulli's reaction to Cheyne's treatise see R. Hall, *Philosophers at war*, p. 132.
[464] I. Newton, *Opticks: or, A Treatise of the Reflexions, Refractions, Inflexions and Colours of Light*, *Also two treatises of the species and magnitude of curvilinear figures* (London, 1704). See N. Guicciardini, *Isaac Newton on Mathematical Certainty and Method,* pp. 367-68.
[465] R. Hall, *Philosopher at War*, pp. 146-167.
[466] *Acta Eruditorum*, January 1705, pp. 30-6.

At first sight, Leibniz's statement does not look mischievous. Its implications are nonetheless ambiguous, as the events that followed demonstrate. Indeed, the comparison between Cavalieri and Fabri, which in Leibniz's analogy stood for himself and Newton respectively, was not neutral and subtly implied the priority of the former's achievements over the latter. It was only six years later that one of his disciples, John Keill, drew Newton's attention to the review, though it is not clear when exactly the latter was first aware of the offending text. Whether or not he had been aware of the review beforehand, Newton immediately took umbrage at being compared to Fabri against Leibniz's Cavalieri.[467]

Keill would become the most ardent of Newton's disciples, and Johann Bernoulli would later christen Keill Newton's "ape". In the 1690s he had studied mathematics under David Gregory, first in Edinburgh and then in Oxford. Keill gave pioneering lectures on Newtonian experimental philosophy at Oxford, and was appointed deputy to the Sedleian professor of Natural Philosophy in 1699. He did not acquire the coveted position of Savilian Chair of Astronomy when Gregory died in 1708, but did so four years later, by which time he had become an exemplary confidant of the President of the Royal Society. Gregory played a key role in introducing Keill to Newtonian mathematics and also to Newtonian philosophy. In time, Keill's willingness to display unconditional and public adherence to Newtonian values would make him the perfect defender of Newton in the priority dispute that he himself did so much to create.

The general facts of the priority dispute are well known. In 1710 Keill published in the *Philosophical Transaction*s a paper on the laws of centripetal force in which he publicly claimed that Newton was the first inventor of fluxions while Leibniz's calculus was a mere derivation (the work was supposed to be published in 1708 but its publication was delayed).[468] That attack, which resembled the allegations already formulated by Fatio in 1699, was reinforced by a letter that Keill addressed to Newton himself in April 1711 alerting him to Leibniz's unsigned review of *De*

[467] See R. Hall, *Philosophers at War*, pp. 138-141.
[468] John Keill, "Epistola ... de Legibus Virium Centripetarum", *Philosophical Transactions* 26 (1708): 185. See R.Hall, *Philosophers at War*, p. 162.

quadratura curvarum.[469]Keill's action produced the desired effects, and he stung both Newton and Leibniz into action. On the one hand, Leibniz was irritated by Keill's public accusation and, acting through the institutional means of the Royal Society, demanded a public retracation of that libellous statement.[470] On the other hand, Newton, after acknowledging Leibniz's review for the first time, claimed to have even "more reason to complain of the collectors of ye mathematical papers in those Acta then Mr Leibnitz hath to complain of Mr. Keil".[471]

Leibniz complaint to the Royal Society did not go unheard, and the English institution quickly asked Keill "to express in a letter his account of this affair".[472] Keill's reply was read to the Royal Society on 24th May 1711 and began with the clear statement that Newton was the "first discoverer of the Arithmetic of Fluxions or Differential Calculus". In his speech, Keill patriotically gave the reasons that, in his opinion, proved Newton's priority over Leibniz, and he remarked that the brief exchange between the two mathematicians had certainly inspired "Leibniz's very sharp mind" to devise a similar method. In his letter Keill made use of detailed elements of Newton's mathematical history that he could not have known by himself and that presumably came from his master.[473] Newton directly participated in the drafting of the letter, and a copy preserved among Newton's papers in the University Library, Cambridge, presents emendations in Newton's hand. Moreover, Keill's arguments resemble very much the repetitive narrative that Newton developed a few years later in support of his case against Leibniz. Newton's involvement in the composition of Keill's letter reveals a key element of his broader strategy during the whole dispute. Newton frequently used his disciples – Keill in particular – as a mask to proclaim his views without, at the same time, exposing his name and risking his credibility. We should bear in mind that at the time he

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[469] On 3rd April 1711, Keill wrote to Newton: "Sr. I have here sent you the *Acta Lipsiae* where there is an account given of your book, I desire you will read from page 39 at these words: ceterum autorum non attingit focos vel umbilicos curvarum &c to the end". *NC*, vol. 5, p. 115.
[470] See R. Hall, *Philosophers at War*, pp. 168-179.
[471] *NC*, vol. 5, p. 117.
[472] Sloane to Leibniz, *NC*, vol. 5, p. 132.
[473] Keill's conduct and language became increasingly and publicly xenophobic, and he noted that "if it was proper for those of Leipzig to pin on Leibniz another's garland, it is proper for Britons to restore to Newton what was snatched from him, without accusations of slander." *NC*, vol. 5, p. 143.

was not only a well-known mathematician and natural philosopher but also the Master of the Mint and the president of the Royal Society.[474]

Leibniz devised a similar strategy to counterattack his intellectual enemy. During the 1710s, the German philosopher increasingly enlarged his circle of disciples, entrusting them with important tasks and responsibilities. The form of the affiliation to their master of each of Leibniz's disciples generally presented similar characteristics: firstly, talented pupils educated in the Leibnizian philosophy were introduced to the master through the mediation of trusted intermediaries; then, Leibniz patronized their careers by supporting their appointment to important university positions. Finally, the disciples became an integral part of the Leibnizian system. Christian Wolff and Jacob Hermann entered Leibniz's orbit through a similar process. The former came into direct contact with Leibniz in 1704 thanks to the mediation of Otto Mencke, the editor of the *Acta eruditorum.* Two years later, Leibniz recommended him for a post at the University of Halle. Hermann, on the other hand, was a pupil of Jakob Bernoulli in Basel; Leibniz interceded on his behalf to get him the mathematical chair in Padua in 1707 and in Frankfurt an der Oder in 1713. After the initial contact, both Wolff and Hermann supported, developed, and promoted Leibniz's views. Wolff, for example, was assigned with the important task of reviewing mathematical books for the *Acta eruditorum,* though most of his texts were edited by Leibniz himself before going into print. Nonetheless, none of Leibniz's disciples established an all-absorbing relationship with the German mathematician; on the contrary, sometimes they resulted in awkward misunderstandings. This was the case in Leibniz's relations with Hermann, and he became deeply concerned about the latter's excessive admiration for Newton.[475]

In the 1710s the disciples had a crucial role in igniting the gunpowder of the cultural war that followed. Leibniz and Newton increasingly strengthened their alliance with those talented

[474] P. Fara, *Life After Gravity: Isaac Newton's London Career* (Oxford University Press, 2021).
[475] In 1716 Brook Taylor wrote to William Jones: "By my correspondence with M. Monmort I find Herman [sic] is not of Bernoulli's party, but is rather under his displeasure". S. P. Rigaud, *Correspondence of scientific men of the seventeenth century 2 vol.* (Oxford: Oxford University Press, 1841), vol. 1, p. 280.

mathematicians who shortly afterwards became crucial elements of their respective strategies. Most of the time, the disciples acted according to their masters' dispositions; sometimes, however, they operated autonomously. Inspired by intense intellectual and occasionally nationalist commitments, correspondence networks, academies and scientific journals became the battlefields of a war that threatened to divide the Republic of Letters. While the Royal Society – with Newton at its helm – and the *Philosophical Transactions* supported the English mathematician and his disciples, the newly founded Royal Prussian Academy of Sciences – of whom Leibniz was president – and the *Acta Eruditorum* championed the German philosopher, giving voice to his ideas and substantiating his plans.

Role-play

The priority dispute erupted in 1711, when both Leibniz and Newton, pushed by their respective acolytes, joined the controversy and took an active part in the leadership of the two parties that their disciples had contributed to creating in the previous years. As several clues suggest, the two mathematicians had already worked behind the scenes to devise a proper strategy against their competitor. John Keill had a crucial role in the outbreak of the controversy; at the same time, another important figure, William Jones, worked in the rear to prepare the ground for the events that followed. Two years after the publication of Newton's *Opticks*, Jones – a self-taught mathematician and a skilful bibliophile – published the mathematical textbook *Synopsis Palmariorum Mathesiosis* (1706). Jones's work, intended as an introduction for beginners in mathematics, was based on the notes that he had taken as a teacher in the coffee houses of London and included important topics such as the differential calculus and infinite series. The *Synopsis* also introduced the symbol π in its modern form. Jones's mathematical knowledge captured Newton's attention, and the two mathematicians interestingly met for the first time just after that publication. Even more captivating for Newton was Jones's acquisition in 1708 of John Collins's extensive

library and archive, which contained several of Newton's mathematical letters and papers composed in the 1670s.

In 1711, under Newton's supervision, Jones edited the *Analysis per Quantitatum Series, Fluxiones, ac Differentias: cum Enumeratione Linearum Tertii Ordinis*, the first systematic discussion of Newton's calculus to circulate in public. Jones's work collected four of Newton's mathematical treatises: *De Quadratura curvarum* and the *Enumeratio*, which first appeared in *Optiks* in 1704; *Methodus Differentialis,* which Newton had composed as early as 1676 but had never formally published; and *De Analysi*, written in the summer of 1669.[476] The *Analysis per Quantitatum Series, Fluxiones, ac Differentias* also included a sampling of correspondence related to Newton's work on the calculus. As Jones explained in the *Praefatio Editoris*, the presence of those letters was crucial to date Newton's mathematical discoveries back to the 1660s and proved that other mathematicians like Collins and Barrow could indirectly witness his priority.[477]

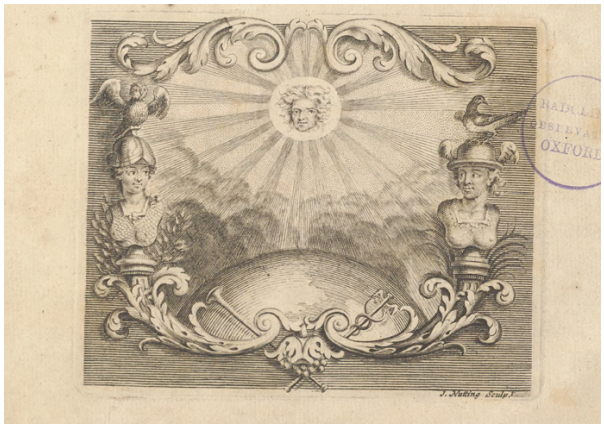
Besides the clear intent to claim Newton's priority in the invention of the calculus, Jones's *Analysis* also aimed at depicting a glorified image of the English mathematician and of his work. To this end, Jones resorted to every means at his disposal, including the use of illustrations and engravings that adorn the text. The engraving that opens the work and that represents a god-like Newton gazing down from heaven, was clearly aimed at deifying the image of the English mathematician. A similar image is reproduced in three more vignettes that appear at the end of *De Quadratura*, the *Enumeratio,* and the *Methodis*. In these last three cases, Newton appears in the shape of a young boy while the frontispiece illustration depicts a man in his mature age, as if to stress visually Newton's young age at the moment of the composition of the three mathematical treatises and of the *Opticks*. Indeed, the vignette includes the representation of some scientific

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[476] As an appendix to the *Analysis per quantitatum series, fluxiones, ac differentia*, Jones added Newton's *Tractatus de quadratura curvarum*, which was a shortened version of the work on analytical calculus written by Newton in 1691. Both the first and the second edition of the *Analysis per quantitatum* published respectively in 1711 and 1723 did contain a preface written by Jones. See Guicciardini *Isaac Newton on Mathematical Certainty and Method,* pp. 369-372; R. Hall, *Philosophers at War*, pp. 170-172, 183-185. D. R. Bellhouse, "The deification of Newton in 1711", *BSHM Bulletin: Journal of the British Society for the History of Mathematics*, 29:2, 2014, pp. 98-110.

[477] I. Newton, *Analysis per Quantitatum Series, Fluxiones, ac Differentias: cum Enumeratione Linearum Tertii Ordinis* (London: ex officina Pearsoniana, 1711), *Prefatio editoris* by W. Jones.

instruments – the reflector telescope, a prism, and a mirror – used by Newton from 1664 to 1672 for his optical experiments.

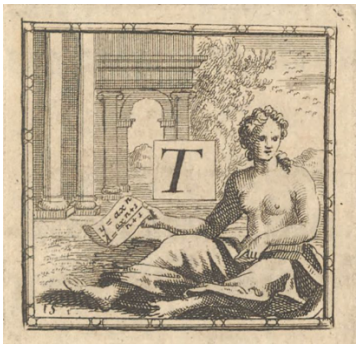


Frontispiece vignette representing Newton in his mature age



Vignette representing Newton as a young boy

Secondly, the engravings that decorate the initial letters of the *Praefatio Editoris* and of the *Enumeratio linearum* were intended to stress the relevance of Newton's method. The two vignettes, indeed, represent two classical female figures that hold in their hands a cartouche revealing two mathematical formulas – Regula I as expressed in *De Analysi* in the first case and the integration of an irrational equation in the second case. A third engraving decorates the initial letter of the *Introductio ad Quadraturam Curvarum;* in this case, however, the illustration depicts a scene in which a young man bows and kisses the feet of an older man – presumably Newton.



Initial letter of the *Praefatio Editoris*



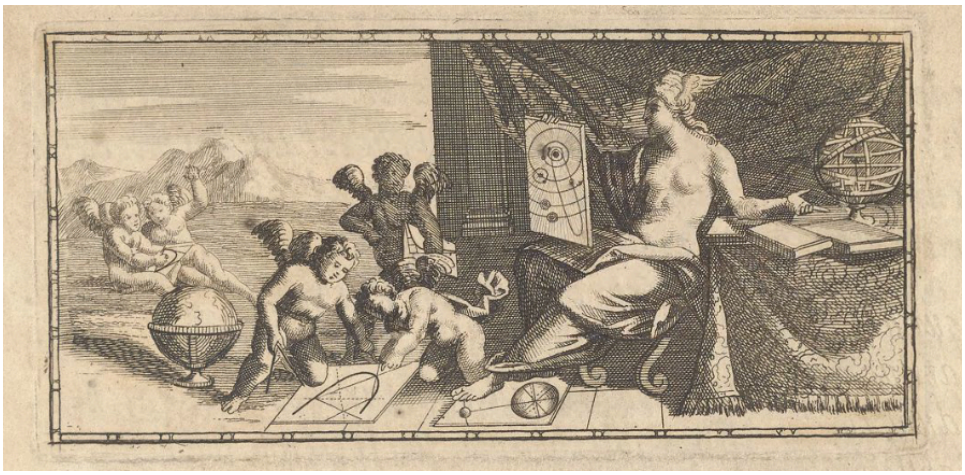
Initial letter of the *Enumeratio linearum*

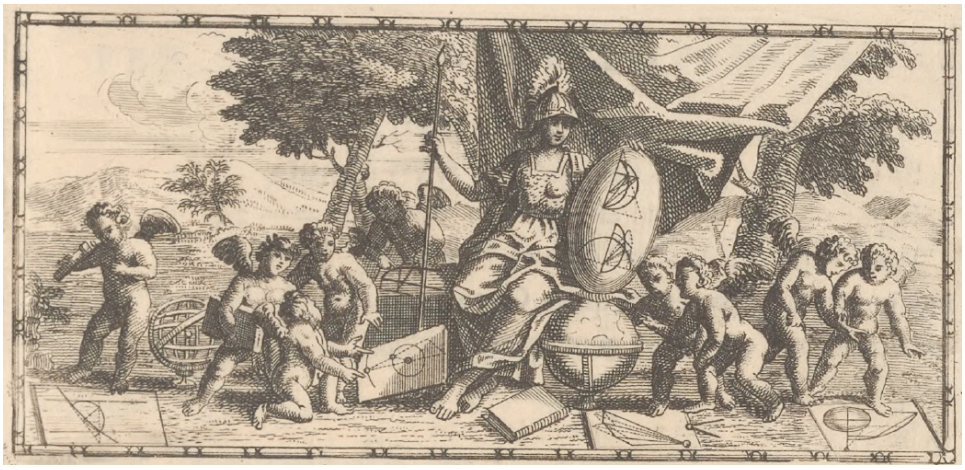


Initial letter of the *Introductio ad Quadratura*

Finally, three engravings placed before the titles of *De Analysis*, the *Enumeratio,* and the *Introductio ad Quadraturam* decorate the pages of Jones's *Analysis*. These three illustrations emphasized several aspects of Newton's mathematical ideas such as the relation between geometry,

astronomy, and natural philosophy. Also, they depicted an oleographic image of Newton and his acolytes.[478]





[478] N. Guicciardini, *Isaac Newton on mathematical certainty and method,* pp. 369-372.



Engravings from Newton, *Analysis per Quantitatum, Series, Fluxiones, ac Differentias: cum Enumeratione Linearum Tertii Ordinis* (1711).

Jones's publication of Newton's work, and particularly the early *De Analysi*, did not mention Leibniz's name at any point, but it stirred Leibniz and Bernoulli to respond. The publication not only facilitated the election of its editor as a fellow of the Royal Society; it also anticipated in many aspects the *Commercium Epistolicum*, the official report drafted by the English institution at the end of 1712 to shed light on the invention of the calculus and terminate the quarrel. The special committee appointed to inspect letters and papers relating to the dispute between Leibniz and Keill was initially composed of six fellows of the Royal Society: John Arbuthnot, Abraham Hill, Edmond Halley, William Jones, John Machin, and William Burnet. In the weeks following that appointment, the committee was extended by five further members: Francis Robartes, Mr Bonet – the King of Prussia's Minister, Abraham de Moivre, Francis Aston, and Brook Taylor. The relationship that linked Newton with each of the committee's members was hardly neutral – most of them were acolytes, allies or colleagues, and their grasp of the technical niceties of the issues was sometimes very marginal. As is well known, Newton himself drafted the bulk of the report, and the outcome of the historical research that underpinned it was distinctly in his favour. Not only did it proclaim the English mathematician as the first inventor of the calculus; it also exonerated Keill from Leibniz's accusations.[479]

[479] N. Guicciardini, *Isaac Newton on mathematical certainty*, pp. 372-381; Hall, *Philosophers at War*, pp. 168-201.

The *Commercium Epistolicum* did not formally accuse Leibniz of plagiarism, yet it elicited a strong reaction from the German side. It was Johann Bernoulli who informed his master about the Royal Society's report, notifying him about the sentence of that trial: "you lose the case, you are condemned".[480] In his letter, the Swiss mathematician also spurred Leibniz to reply to Newton's "medley of letters" with his documents and truth, although he explicitly begged Leibniz for his own name to be left out of that dispute in order to preserve his relationship with Newton. Leibniz's reply to Bernoulli expressed two different nuances of the master-disciple relationship: on the one hand, he respected Bernoulli's request, justifying it by accusing Newton of having captured Bernoulli's sympathy "with his blandishments".[481] On the other hand, however, Leibniz was clearly probing Bernoulli about his true allegiance and was persuading him to take sides (as Newton later accused him of doing). Leibniz remained reliant on the support of his disciple but demanded a display of loyalty in return for his own patronage. By appealing to Bernoulli's "honesty and sense of justice", he assigned to him a delicate task, namely to "make it evident to our friends that in your opinion Newton's calculus was posterior to ours, and say this publicly when opportunity serves".[482] On this occasion Leibniz referred to "our" calculus, stressing the fact that his mathematical achievements were the result of their close collaboration. That was not an isolated episode; already in 1694, indeed, Leibniz had attributed the calculus to Johann and Jacob Bernoulli as well as to himself.[483]

On 18th July 1713, Leibniz published anonymously the *Charta Volans*, a pamphlet that responded to "the little volume lately published in England in which certain people endeavour to claim the first discovery of the differential calculus for Newton".[484] At the time of its composition, Leibniz had not yet seen the *Commercium Epistolicum* – or it was tactically useful for him to say

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[480] *NC*, vol. 6, p. 3.
[481] Bernoulli's letter dated 7th June 1713 (NC, vol. 6 pp. 3-5) was reprinted as the verdict of an unnamed "leading mathematician" who had been asked to pass judgement on the matter. Bernoulli's letter was circulated anonymously, though Leibniz did not leave out from the text certain details that eventually gave up Bernoulli as its author. See Hall, *Philosophers at War*, pp. 198-201.
[482] *NC*, vol. 6, pp. 7-9.
[483] G. W. Leibniz, *Sämtliche Schriften und Briefe. Dritte Reihe, Mathematischer, naturwissenschaftlicher und technischer Briefwechsel* (Berlin-Brandenburgische Akademie der Wissenschaften; Akademie der Wissenschaften zu Göttingen, 2004), Vol. VI, p. 37.
[484] *NC*, vol. 6, p.18.

so; his assumptions were based only on the detailed accounts that his disciples – Bernoulli and Wolff – had reported to him. As it is clear from this episode, Leibniz relied on trusted allies that in his absence became his ears and eyes. Wolff was not only important in mediating between the English intellectual world and Leibniz; he was also crucial in printing and circulating his master's leaflet all over the Continent. The *Charta Volans* was translated into several languages and distributed to various journals like the *Journal Literaire* of The Hague in France. In the previous months, that same journal had printed a letter – *Lettre de Londres* – in which Keill had anonymously given his account of the history of the infinitesimal calculus as narrated in the *Commercium Epistolicum*. Like many before them, both Leibniz and Keill published their papers anonymously. Although the author of a certain report might be identifiable from the content, context and style of his text, anonymity was a powerful means of circulating information without formally exposing the author to criticism and controversies.[485]

At first, Newton did not react to Leibniz's leaflet; once again, it was his disciple Keill that added fuel to that fire. In a letter dated 8th February 1714, Keill warned Newton about the wide circulation of the *Charta Volans* and asked his master to give his opinion about what was "needful further to be done in answer to Mr Leibnits". This passage further reveals the role-play between master and disciple: the latter rarely acted without his master's consent; instead, he waited for Newton's dispositions and reassured him that he would follow his orders to the best of his ability.[486] In his reply, Newton duly told him what to do:

> If you please when you have it, to consider of what Answer you think proper, I will within a Post or two send you my thoughts upon the Subject, that you may compare them w^th^ your own sentiments & then draw up such an Answer as you think proper. You need not set your name to it. You may write either in English or in Latine & leave it to Mr Johnson to get it translated into F[r]ench. Mr Darby will convey your Answer to the Hague.[487]

[485] In 1697, for example, Johann Bernoulli had used the notorious expression "tanquam ex ungue leonem" ([I recognize] the lion's claw) about Newton's anonymously submitted solution to Bernoulli's challenge regarding the Brachistochrone curve.
[486] Keill to Newton, *NC*, vol. 6, p. 62.
[487] Newton to Keill, *NC*, vol.6, p.79

Despite Keill's deferential attitude, Newton's reply highlights the nature of the collaboration between master and disciple. Later, and based on his "thoughts", Newton allowed Keill to draw up the main draft of the text and sent it to London; Newton was then advised to "change add or leave out anything".[488] Their combined efforts eventually resulted in the publication of Keill's "answer" in the *Journal Litéraire* for July and August 1714.

It is interesting to note that Keill's reply was not published anonymously as Newton had suggested doing in a previous missive; on the contrary, the disciple later indicated that he was enthusiastic about "putting my name to it, for I have said nothing but what is fully made out, and they have on the contrary have thrown all the dirt, and scandal they could without proving anything they have said, and therefore they thought it best to conceal their names".[489] During the first two decades of the eigtheenth century, Keill linked his name indissolubly to his master, thus enjoying all the disadvantages and advantages of the case. On the one hand, the disciple exposed his name and reputation to the attacks of the Leibnizian side;[490] on the other hand, he could boast about his proximity to an intellectual giant who was also President of the Royal Society and Master of the Mint. With his enemies, Keill was ruthless: he spared none of them, acting most of the time like Newton's ambassador of war.[491]

A precarious balance

The use of Keill as a buffer of deniability between himself and his critics represented only one aspect of the complex strategy that Newton had devised to fight his intellectual enemies. While

[488] Keill to Newton, *NC*, vol.6, p. 138.
[489] Keill to Newton, *NC*, vol.6, p. 114.
[490] In a letter to Wolff, for example, Leibniz described Keill with a sharp comment: "Since Keill writes like a bumpkin, I wish to have no dealings with a man of that sort. It is pointless to write for those who respond only to his bold assertions and boasting, for they do not examine the substance […] I think of knocking the man down, some time, with things rather than words". *NC*, vol. 6, pp. 222–3.
[491] About the article published by Bernoulli in the *Journal Litéraire,* Keill wrote to Newton: "I have read both pieces ... inserted in the Journal Litéraire and I think I never saw anything written with so much impudence, falsehood and slander as they are both. I am of the opinion that they must be immediately answered and I am now drawing up an answer which I will finish as soon as I hear from you". (*NC*, vol. 6, p. 106). In the following letters, Keill also criticized Leibniz's errors in his *Tentamen* (*NC*, vol. 6, p. 141, 148): in addition to mathematics, the cultural war between Leibniz and Newton was also played in the field of gravity. See Hall, *Philosophers at War*, pp. 202-231.

Keill fought trench warfare against Newton's opponents, the French mathematician Abraham De Moivre acted as a peacemaker who established a back of house dialogue between the two factions. Newton, of course, directed his disciples behind the scenes. The relationship between De Moivre and Newton owed much to the mediation of Edmond Halley years before the outbreak of the priority dispute. It was only in the context of the controversy with Leibniz, however, that it assumed importance and significance. Newton highly appreciated De Moivre's mathematical skills and, most importantly, he valued the French mathematician's diplomatic relationships. De Moivre's network, indeed, embraced many intellectuals of the time, and included Johann Bernoulli. That link became crucial to mediate between the two sides of the fight.

In the context of the priority dispute, De Moivre was a member of the committee that edited the *Commercium Epistolicum*, and he participated actively in the exchange of fire that followed its publication. In 1713, in response to the Royal Society's leaflet, Bernoulli published a paper in the *Acta Eruditorum* of February-March in which he discredited Newton's mathematical skills and cast sharp shadows on his claim of priority as asserted in the *Commercium Epistolicum.* Newton dealt with that accusation with a twofold strategy: on the one hand, he urged Keill to include his thoughts on Bernoulli's paper in the official answer that the disciple was drafting in response to the *Charta Volans*. On the other hand, he asked De Moivre to intervene diplomatically as a bridge between the two sides of the Channel. The two disciples acted strictly according to Newton's instructions.

The letter that De Moivre wrote to Johann Bernoulli on 28th June 1714 provides substantial insight into Newton's strategy. At the time, Newton knew that Bernoulli was a false friend but did not want to engage with him directly – presumably because he did not want to dignify Bernoulli by engaging in a dispute with him or because he did not personally want to engage in a dispute. The latter might have been for the usual reasons he gave in such circumstances, but more likely it was because it would open up a front in the contest that he could not manage to his advantage. De Moivre opened his letter with words of praise for the Swiss mathematician and thanked him for his skilful remarks on Newton's *Principia*; on the other hand, however, he seized the opportunity to

hint at Newton's anger at the insinuations included in the *Charta Volans*, which publicly accused him of plagiarism. De Moivre's letter continued with a diplomatic fencing assault and, through a clever dissimulated strategy implied Newton's alleged ignorance of the attack that Keill was preparing in response to the *Charta Volans*.[492] This passage indicates the importance of discipleship in Newton's strategy: Keill and De Moivre represented respectively the stick and the carrot that their master was using to tease Bernoulli. By referring to a personal conversation with Newton, in the final part of the letter De Moivre reasserted his master's esteem and respect toward Bernoulli, promised him a copy of the second edition of the *Principia*, and remarked the fact that Newton was not offended by his behaviour.

Bernoulli answered De Moivre's letter on 24th July 1714 with an exercise in dissimulation. At first glance, he welcomed favourably De Moivre's signs of a thaw; his letter, indeed, began with a tone of courtesy that manifested his respect and esteem toward Newton. The content of the letter was cordial, too. Bernoulli depicted himself as a *super partes* character in the context of the priority dispute; in this sense, he even thanked De Moivre for not suspecting his association with Leibniz's side and hoped "for the peace to be re-established between these two gentlemen or rather that this quarrel never arose".[493] In many passages he referred to his discoveries, which were not written "to supply weapons against Mr. Newton" but rather "for the sake of the truth, or for the advancement of science".

Bernoulli reserved a vitriolic comment for the "*plume empoisonnee*" of Newton's disciples, in particular George Cheyne and Keill. The former was accused of having published Bernoulli's own discoveries without mentioning him; the latter was criticized for his unfair attacks, "all the more so since the great Newton himself, whose defence he [sc. Keill] assumes, considered him worthy of his approval". Bernoulli did not include himself in the array of partisans that initiated the

[492] "On dit que M. Keil en fait son affaire, et qu'il paroitra au premier jour une piece de luy qui doit servir de reponse aux papiers ecrits depuis peu en faveur de Mr Leibnitz contre Mr Newton". *NC*, vol. 6, p. 151.
[493] "Que la paix fût retablie entre ces deux Messieurs ou plûtôt que cette querelle n'eut jamais été suscitée". *NC*, vol. 6, p. 153.

war. On the contrary, not only did he assert his ignorance of the *Charta Volans,* but he also declared his intellectual independence. With typical self-confidence, he also claimed his share of a glory that Newton and Leibniz were keeping just for themselves; "if They, for whom their partisans mutually declared war on each other, threw the first stone, we can boast of having built most of this Edifice, which Mr. Leibnits Himself recognizes somewhere in the acts from Leipzig".[494] Bernoulli concluded his letter to De Moivre with an amicable message for Newton:

> It suffices that I declare loudly that I never intended to cause the slightest sorrow to Mr. Newton, but on the contrary that I seek every opportunity to show the very deep esteem that I have for him and the great esteem that I make of its rare merit; this is what I urge You to assure, giving Him my respectful compliments.[495]

Was Bernoulli's message sincere? Or was he only playing De Moivre and Newton? In those years Bernoulli and Wolff wrote similar messages to Leibniz: firstly, they encouraged him to answer the English accusations, because "most people may deduce from [your] silence that the English case is a good one";[496] secondly, they urged Leibniz to edit a sort of counter-*Commercium Epistolicum* that would produce documents (they hoped) favourable to Leibniz;[497] finally, they suggested to him various ways of creating trouble for their adversaries. Leibniz for his part was convinced that "Newton's toadies" – especially Keill – were not worthy of a reply, but he welcomed Bernoulli's proposal to publish some problems that would cause difficulties for Newton,[498] a solution that allowed Leibniz to hide both the purpose of his attack and his own name. The problem, indeed, had to be presented by Bernoulli as if it was "requested by a friend".

The Leibnizian front was united against its enemies by the same ideals. Often, however, Bernoulli, Wolff, and Leibniz himself showed uncertainty about who was the real target of their

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[494] "Pendant qu'on dispute a qui d'eux appartient la gloire de quelques inventions, je croi que nous autres pourions bien pretendre aussi de participer a cette gloire; car si Eux, pour qui leurs partisans se sont mutuellement declaré la guerre, ont jetté la premiere pierre, nous pouvons nous vanter d'avoir bâti la plus grande partie de cet Edifice, ce que Mr. Leibnits Lui même reconnoit quelque part dans les actes de Leipsic; cependant les partisans le dissimulent et ne nous veulent point admettre à la participation de la moindre partie de la gloire disputée". *NC*, vol. 6, pp. 153-4.
[495] *NC*, vol. 6, p. 155.
[496] Wolff to Leibniz, *NC*, vol. 6, pp. 206-7.
[497] Bernoulli to Leibniz, *NC*, vol. 6, pp. 203-4.
[498] Bernoulli to Leibniz, *NC*, vol. 6, pp. 203-4.

attacks. From the analysis of their correspondence, it emerges that Keill was the main objective of the Leibnizian's hostility. At this point it is relevant to recall that Leibniz was a librarian, philosopher, historian but most importantly an experienced diplomat, with a commitment to the creation of a close-knit Republic of Letters. It was important for him to abide by older conventions according to which one avoided accusing a powerful individual of bad behaviour as much as one could; instead, he blamed seconds or – as in court culture – royal advisors. In a letter dated 2nd July 1715, Bernoulli explicitly referred to the "controversy which rages between you and Keill",[499] while Newton was not mentioned at all.[500] Newton himself in a letter to Conti mentioned "the dispute between Mr Leibnitz & Dr Keill".[501] Besides, during the dispute Newton acted only behind the scenes while Keill exposed his name on his master's behalf. In 1715, indeed, Keill was asked by Halley – acting on behalf of Newton – to publish a French translation of the *Commercium Epistolicum* in the *Journal Litéraire.* Newton, Halley wrote, "is unwilling to appear in it himself, for reasons I need not tell you, and therfore has ordered me to write to you about it, who have been his avowed Champion in this quarrell; and he hopes you will gratifie him in this matter by the first opportunity".[502]

Notwithstanding the disguise, for Leibniz and his disciples it was clear that Keill fought "not with his own weapons, but with Newton's".[503] And in early 1715, Leibniz told Bernoulli that Newton had "at last entered the ring himself, in order to fight under his own name, and laid aside his mask"[504]. The person who convinced Newton to provide his own account of the events was Antonio-Schinella Conti, an Italian mathematician and philosopher who travelled to England with the intention of supporting Leibniz's cause.[505] By the spring of 1715 the dispute between the two mathematicians had become increasingly fractious, and many intellectuals were eager either to

[499] Bernoulli to Leibniz, *NC*, vol. 6, p. 229.
[500] These non-mentions of various people might be read as tactics – at the time it was unclear whether these letters might be later published and weaponised. Deniability was key.
[501] Newton to Conti, *NC*, vol. 6, p. 285
[502] Halley to Keill, *NC*, vol. 6, p. 242.
[503] Wolff to Leibniz, *NC*, vol. 6, p. 180.
[504] Leibniz to Bernoulli, *NC*, vol. 6, p. 318.
[505] Conti expressed his intention to Leibniz in a letter dated April 1715 in *NC*, vol.6, p. 215.

resolve the dispute or to take part in the fight on one side or the other. Leibniz sought new supporters for his cause, and enrolled disciples such as Bernoulli to identify potential allies. In July Bernoulli wrote to Leibniz about the recruitment of one of his pupils – John Arnold – that had "shown and proved to me particularly his intelligence, not only in common matters but also in the higher branches of our analysis".[506] The new conscript made great progress in differential and integral calculus; "you will have in him, when he returns to his country, your defender against envious and malicious men" – continued Bernoulli – "since I have explained to him the state of the whole controversy". Bernoulli was acting here as an intermediary between the master, Leibniz, and new potential disciples.

On the other hand, Newton's circle was growing in number and importance, drawing in acolytes from across Europe. On many occasions, Newton or his entourage appealed to selected candidates by offering them prestigious rewards, usually the fellowship of the Royal Society.[507] His growing fame attracted intellectuals interested in supporting him at all costs, while those drawn to his cause – including scholars, noblemen and diplomats – also enhanced his fame. At its most extreme, this sentiment took the form of a sort of worship, with Newton becoming a divine figure and his admirers turning into devotees ready to visit his house as a place of pilgrimage.[508] Newton prized those opportunities and used some of his visitors to spread his campaign against Leibniz abroad. An interesting case of this sort was that of Francesco Bianchini, an Italian polymath who in 1713 travelled to England with the express and only purpose of visiting the great English mathematician. After meeting Newton, Bianchini left England with "gifts of an outstanding

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[506] Bernoulli to Leibniz, *NC*, vol. 6, p. 229.

[507] Among others, this was the case of Pierre Varignon, who after being elected fellow of the prestigious institution, wrote a letter to Newton manifesting his great esteem and admiration. See *NC,* vol. 6, pp. 187-88.
See also A. R. Hall, "Further Newton Correspondence", *Notes and Records of the Royal Society of London*, Vol. 37, No. 1 (Aug., 1982), pp. 7-34, in particular: Johann Jakob Scheuchzer to Newton (April 1706), p. 16; Lodovico Antonio Muratori to Newton (24 May/4 June 1716), p. 23; Francesco Torti to Newton (20/3 July 1716), p. 24; Giovanni Giuseppe, Marquis Orsi to Newton (25 April/6 May 1717), p. 24; Antoine De Jussieu to Newton (12/23 January 1719), p. 27.

[508] See the following letters in A. R. Hall, "Further Newton Correspondence": Albert De Sallengre to Newton (27 October/7 November 1718), p. 26; Stefan Engedi to Newton (1 August 1720), p. 28; Johann Petrus Biester to Newton (13 August 1725), p. 31; Ferdinand Ernst Von Herberstein to Newton (15/26 October 1709), p. 17.

intellect": a copy of the *Opticks*, a copy of William Jones's collection of Newton's mathematical works, and five copies of the *Commercium Epistolicum* clearly intended to spread Newton's side of the story abroad. Also, when in Italy the Italian polymath was provided with further material to carry on his anti-Leibnizian propaganda, as reported in his letter to Newton dated May 1714:

> The copies of Mr. Keill's apologetic writings, vindicating your priority in that outstanding discovery in analysis against Mr. Leibniz, which were sent to me by Mr. Richard Waller, Secretary of the Royal Society, I have taken care to distribute to the men outstanding in geometry to whom they were addressed, namely Guido Grandi at Pisa, Fr. P. Galliani at Rome, and Mr. Manfredi at Bologna.[509]

Newton's appeal mesmerized intellectuals of all kinds, including some of Leibniz's supporters like the Abbè Conti.[510] In 1716, Leibniz's entourage began to raise doubts about Conti's loyalty – Remond de Monmort warned Leibniz about Conti's half-hearted support over the summer of 1715.[511] Leibniz himself eventually acknowledged that Conti seemed "inclined to take sides with his new friends".[512] Around that same time, Bernoulli's allegiance to Leibniz's cause began to waver, too, especially when he realized that Newton was aware of his role as the author of the *Epistola pro eminente mathematico* published in the *Acta Eruditorum* for 1716. That letter, indeed, was clearly supposed to have been anonymised although Christian Wolff, who prepared the pro-Bernoullian document for publication, left in a first-person pronoun that revealed Bernoulli as its author. In a letter to Leibniz, Bernoulli legitimately wondered "how Newton could have known that he was the author of that letter, when actually "no living soul knew that I had written it except you to whom it was written, and I, by whom it was written".[513] Besides that episode, Bernoulli was increasingly manifesting his willingness to claim his intellectual independence from his master. In a letter dated 3rd July 1716, he bluntly asked Leibniz to acknowledge publicly his merits in arriving "at the art of summation and integration without the help of anyone" and his role in increasing "the

[509] Bianchini to Newton (May 1714), in A. R. Hall, "Further Newton Correspondence", p. 21.
[510] This case recalls the events that turned Princess Caroline – the archetypal Leibnizian follower – into a supporter of Newton and Clarke. The English mathematician and his acolyte did not make of Caroline a Newtonian disciple, but they nonetheless "cured" her affection for Leibniz.
[511] Arnold to Leibniz, *NC*, vol. 6, p. 275; Nicolas Remond to Leibniz, *NC*, vol. 6, p. 297
[512] Leibniz to Bernoulli, *NC*, vol. 6, p. 318.
[513] Bernoulli to Leibniz, *NC*, vol. 6, p. 339.

fame of the infinitesimal calculus" by his own work. In return, Bernoulli would gladly admit Leibniz's own skilfulness in the art of summation and integration, and even in the art of using exponentials.[514]

This passage highlights once again the difference existing between Newton and Leibniz's disciples: on the one hand, Keill was unconditionally devoted to his master and fought his battles even if that meant jeopardizing his name and losing his credibility. Indeed, this was the perennial problem of a disciple: to escape the anxiety of influence and to assert his own, independent authority. On the other hand, Bernoulli did not see himself as a disciple in the conventional sense and was very careful not to expose his attachment to Leibniz too openly, resorting often to anonymity and other stratagems that kept his identity hidden. In his letters, the Swiss mathematician often emphasized his interest in promoting his mathematical ideas only "pour l'amour de la verité", while he could not understand some of Newton's disciples, who did not endorse an argument in order to "defend the truth", but only to preserve the glory of their nation and the credibility of their master.[515]

Leibniz's death in November 1716 represented a crucial turning point for the dispute. After that event, the balance between the two parties was irrevocably compromised. Bernoulli, who had tried to recover Newton's trust even before Leibniz's death, after 1716 increasingly distanced himself from his former master and his choices. In a letter to Remond de Monmort, for example, he tried to convince his interlocutor that he had never intended to deceive the English mathematicians with tricky challenges like the problem that Leibniz had proposed to his rivals in January 1716.[516] On the contrary, he assured Monmort that he had never missed the occasion to proclaim his great esteem for Newton, with which he wished to establish a good and sincere friendship.[517] The

[514] Bernoulli to Leibniz, *NC*, vol. 6, p. 360.
[515] In this passage Bernoulli was referring to Samuel Clarke and to his philosophical dispute with Leibniz.
[516] Actually, it was Bernoulli who on 26th January 1715 had first proposed the issue of a challenge-problem to Leibniz. See the letter from Bernoulli to Leibniz in *NC*, vol. 6, p. 203-4
[517] Bernoulli to Monmort, *NC*, vol. 6, p. 383. See also the letter that Monmort wrote to Newton on March 1718 in *NC*, vol.6, p. 435.

mediation of Pierre Varignon was essential to breaching Newton's wall.[518] The French mathematician, indeed, acted as a pacifier between the two parties and tried to find an agreement so that peace could be restored. Bernoulli eventually denied his support to Leibniz, while Newton assured the Swiss mathematician that he never intended either to mock him or to injure his reputation. Both, of course, were hypocritically playing a role out of self-interest.

Lights and shadows

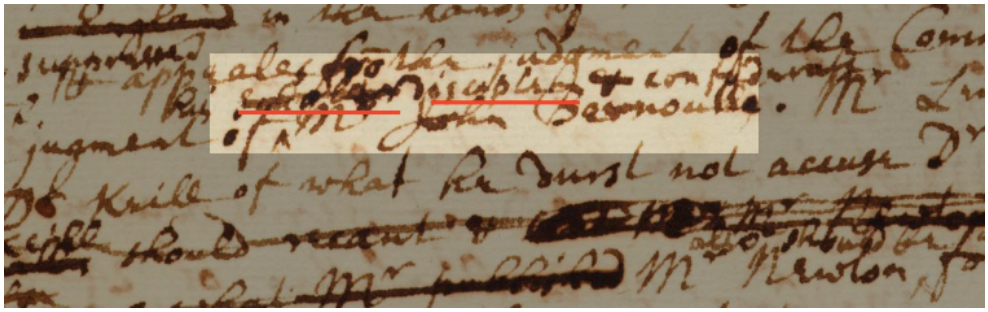
Leibniz's death did not prevent Newton from mounting a final attack that could corroborate once again his version of the facts. After the publication of the "Account of the Book entituled Commercium Epistolicum",[519] which appeared in the *Philosophical Transactions* for 1715, and of the "Observations upon the preceding Epistle", inspired by a letter from Leibniz to Conti dated March 1716, Newton became involved in the publication of key documents in the dispute edited by the French Huguenot Pierre des Maizeaux – the *Recueil de diverses pièces sur la philosophie, la religion naturelle, 1'histoire, les mathématiques* (Amsterdam, 1720). Later, Newton frequently declared that he had had no hand in des Maizeaux's project, although several clues reveal his involvement in the revision of that work.[520] The letters and texts published by Des Maizeaux showed that during the whole dispute, and even after Leibniz's demise, Newton acted from behind the scenes, structuring, editing, and revising most of the documents related to his case. Thanks to the searchable collection of drafts and notes preserved at Cambridge University Library, scholars are now able to see in fine detail how he covertly directed each attack against Leibniz, while his disciples acted publicly on his behalf. This strategy allowed him to slip between hiding and then gradually revealing his authorship of the anti-Leibnizian texts, without risking his name, fame, and credibility.

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[518] See the followings letters (from August 1718 to January 1722) between Varignon and Newton: *NC*, vol. 7, pp. 3-4, 14-17, 62, 90, 104, 119-123, 141, 152, 1590-60, 178, 183.
[519] See N. Guicciardini *Isaac Newton on mathematical certainty*, pp. 381-384; R. Hall, *Philosophers at War*, pp. 261-314.
[520] R. Hall, *Philosophers at war*, p. 242-44.

Newton's whole campaign against Leibniz was heavily reliant on his right-hand men. Still, it is interesting to notice that he never acknowledged publicly the essential role that his disciples played either in the context of the priority dispute or in other circumstances. On the contrary, in his notes Newton stressed the fact that discipleship was unnecessary and even antithetical to his work; he rather preferred to "leave truth to shift for itself".[521] While he denied the participation of disciples in his enterprise, Newton nonetheless made direct references to Leibniz's alleged obsession with cultivating acolytes. According to his view, the German philosopher "spent his life in keeping a general correspondence for making disciples" – a statement that gives a quite accurate indication of how Leibniz established relationships with his acolytes. For Leibniz, Newton noted in a letter to Varignon, it was "as if a Duel, or perhaps a Battel between my soldier-guards [as he calls them] and his Army of Disciples, to whom he happily gives himself up, were a fitter way for deciding the Question of the first inventor than an Appeal to ancient and authentick writings, and Mathematicks must henceforward be filled with Achievements in knight-errantry, instead of Reasons and Demonstrations".[522] Newton's notes from this period on Leibniz's conduct are replete with pejorative references to the latter's disciples as an "army" or a "posse", as to stress not only the large number of people that Leibniz had gathered around him but also their bellicose attitude toward the English mathematician. It is important to highlight that Newton's use of the word disciple was not unsound. In a note referring to Johann Bernoulli, "the chief of his [sc. Leibniz's] disciples",[523] Newton at first wrote down the expression "scholar" but then replaced it with the word "disciple". The English mathematician was truly convinced that the acolytes deployed by Leibniz were public emissaries who acted to contaminate (or bias) the public sphere of the Republic of Letters in favour of their master.

521 The transcription of Newton's notes (MS Add 3968) can be consulted on the Newton's Project: http://dev.newtonproject.ox.ac.uk/search/results?loc=2&idno=3968&sort=id&order=asc
522 *NC*, vol. 7, p. 164.
523 MS Add. 3968, f. 28r.



MS Add. 3968, f, 558r
Cambridge University Library, Cambridge, UK

After the resolution of the priority dispute with Leibniz, even in his old age, Newton did not renounce the cultivation of acolytes. In 1722, on the eve of his eightieth birthday,[524] he met the last of his would-be disciples, the English physician Henry Pemberton. The analysis of the relationship between Newton and Pemberton mainly relies on the latter's works rather than on the correspondence between the two: although a set of Pemberton's letters survived, none of Newton's replies to those missives are available to scholars. An interesting account of the intercourse between master and disciple can be found in the Preface of Pemberton's work *A view of Sir Isaac Newton's philosophy,* published in London in 1728. In that text, the English physician reported that he made the acquaintance of his master in 1722 thanks to the intercession of Newton's physician, Richard Mead. The latter had shown to Newton a paper by Pemberton confuting Leibniz's notion of the force of motion, which had impressed Newton so much that he had assigned to the young physician the revision of the new edition of his *Principia*.[525] Newton's assignment had a significant impact on the evolution of the relationship; the young physician, indeed, had "the honour of his [sc. Newton's] conversation", and "endeavored to learn his thoughts upon mathematical subjects, and something historical concerning his inventions".[526] To fully get the relevance of this aspect, it is important to

[524] Pemberton referred to Newton's "extreme great age" in several points of his preface of *A view of Sir Isaac Newton's philosophy*: in a passage, for example, the young physician underlined that although the age made Newton's memory much decayed, still he perfectly understood his own writings, contrary to what was frequently said from many people. Another passage, instead, referred to the fact that Newton's age and his universal reputation did not render the English mathematician "stiff in opinion, or in any degree elated". H. Pemberton, *A view of Sir Isaac Newton's philosophy* (London, 1728), Preface.
[525] For a full account of the revision of the third edition of Newton's *Principia* see: I. B. Cohen, *Introduction to Newton's "Principia"* (Cambridge University Press, 1971), 265-284.
[526] H. Pemberton, *A view of Sir Isaac Newton's philosophy,* Preface.

stress that in the 1720s Newton was one of the most important personalities of the time while Pemberton was a twenty-eight-year-old physician who had just concluded his studies in medicine.

In his Preface, Pemberton made a glancing reference to the content of his conversations with the master and emphasised several topics notoriously dear to Newton, like the contrast between ancient and modern mathematics and the superiority of geometry over algebra. Pemberton recorded that during their meetings, Newton acknowledged that he had read only a few of the modern mathematicians while he praised authors like Slusius, Barrow, and Huygens; "of their taste, and form of demonstrations", Pemberton noted, "Sir Isaac always professed himself a great admirer: I have heard him even censure himself for not following them yet more closely than he did; and speak with regret for his mistake at the beginning of his mathematical studies, in applying himself to the work of Descartes and other algebraic writers". Pemberton also referred to Newton's admiration for the Spanish mathematician Hugo de Omerique for his "laudable attempt" to restore the ancient analysis, and to his esteem for Apollonius's book *De sectione rationis*.

While the Preface of *A view of Sir Isaac Newton's philosophy* gives interesting hints about Pemberton's motivations for, and the means by which he approached Newton, its Introduction provides a precious perspective for understanding his role in the fulfilment of Newton's scientific project. Pemberton opened his text by mentioning Newton's reluctance to disseminate his work among an amorphous readership, an attitude that had caused his discoveries "to lie very much concealed from all, who have not made the mathematics particularly their study". During his life, Newton "chose rather to explain himself only to mathematical readers" and declined to instruct those who, by not comprehending his method of reasoning, could not be persuaded of the truth of his discoveries. "But now" – Pemberton continues – "since Sir Isaac Newton's doctrine has been fully established by the unanimous approbation of all, who are qualified to understand the same; it is without doubt to be wished, that the whole of his improvements in philosophy might be universally known". Pemberton revealed then the purpose of his enterprise: giving a "general notion" of Newton's inventions to those who, not skilled enough to read his works by themselves,

desired nonetheless to "take great pleasure in tasting of this delightful fountain of science". To this purpose, in his work Pemberton had avoided using "terms of art" as much as possible and had taken care to define the technical expressions that he was obliged to use to make Newton's theories available to a lay audience.[527]

This last point opens to an interesting consideration: why would Newton choose a physician without any formal training in mathematics to explain his philosophy and to edit the third edition of his *Principia*?[528] Following this query, can we define Pemberton as one of Newton's disciples or would it be more appropriate to define him as an editor or populariser of Newton's work? To answer the first question, it is important to consider the stage of Newton's project at the time of his meeting with the young physician. In the 1720s, with the third edition of his work, Newton presumably aspired to render his views available to a wider audience; a non-expert mathematician – who had nonetheless the privilege of conversing with him – would facilitate the mediation between the author and his non-specialized readership. A close analysis of Pemberton's intervention to the third edition of Newton's *Principia* corroborates this point: his key interventions mainly concerned the style of the text, the accuracy of the expressions, and the clarity of reasoning while only occasionally did he engage in substantive issues of mathematics or physics. According to Pemberton, Newton received his remarks with "the utmost goodness" although not all the corrections were incorporated into the printed edition.

Answering the second question, on the other hand, requires the consideration of Newton's attitude to discipleship in more general terms. The complexity of the English mathematician's scientific project entailed the cooperation of different personalities that eventually, concurred to its

[527] H. Pemberton, *A view of Sir Isaac Newton's philosophy,* Introduction, pp. 1-2.
[528] Notwithstanding the lack of any formal training in mathematics, Pemberton had nonetheless proved to be skilled in the subject when in 1722 he had published the *Epistola ad amicum de Cotesii inventis, curvarum ratione, quae cum circulo & hyperbola comparationem admittunt. Londini: Impensis Guil. & Joh. Innys, 1722*, in which he proved Cotes's formulas.

realization. The fact that Pemberton was not mathematically qualified to delve into the technicalities of Newton's work, thus, does not downsize the importance that the young disciple played for his master's cause. Rendering the *Principia* accessible to a lay audience, indeed, represented a crucial part of Newton's enterprise.

Pemberton's introduction to *A view of Sir Isaac Newton's philosophy* helps to understand his role – and, more generally, the meaning of discipleship – in Newton's project. If we look at a broader picture, it also provides interesting hints to reflect on the link existing between mathematics, natural philosophy, and discipleship in the early modern age. Pemberton's words, indeed, recalled the message that philosophers like Copernicus, Kepler, and Galileo had expressed decades earlier: firstly, Newton's willingness to "explain himself only to mathematical readers" resembles very closely the Copernican motto *mathemata mathematicis scribuntur* as expressed in *De Revolutionibus* in 1543; secondly, his need for a "unanimous approbation" of those who are qualified to understand mathematics, brings to mind Kepler's letter to Galileo dated 1597 in which the German astronomer had expressed the necessity to build a network of expert mathematicians to validate the Copernican system with a unanimous agreement; finally, Pemberton's role as a populariser of Newton's philosophy evokes Galileo's disciples who, guided by Castelli, mastered the *Dialogue*'s main arguments before operating a wider dissemination of their master's worldview.

In his letters and notes Newton often expressed disdain for the notion of discipleship, depicting himself as inveterately opposed to its cult and culture. His statements, however, are not entirely consonant with his conduct and actions. In the context of the priority dispute, the English mathematician heavily relied on the support of trusted allies, which acted in various settings and with different tasks. Some of them played a crucial role in the collection, analysis, and production of documents that would support and strengthen Newton's case; others, participated first-hand in the public intellectual duel engaged against Leibniz and his proselytes. Should we attribute Newton's behaviour to his psychological build? Or is it ascribable to the social and intellectual

structures that existed at the time? The answer to explain such dichotomy probably lies in between, namely in Newton's ability to successfully (or unsuccessfully) manipulate these structures according to his own personal preferences. In his correspondence, indeed, Newton often accused Leibniz to cultivate proselytes tasked with planting pro-Leibnizian and anti-Newtonian propaganda in his in-house journals and academies. When needed, however, his action did not differ much from his rival's.

It is important to stress that the disciples' readiness to enter Newton's orbit and to be part of his inner circle play a crucial role in understanding the dynamics that concurred to the birth of the relationship. Most of them, indeed, approached the master with flattering letters and skillful treatises to endear themselves to Newton. In this sense, John Flamsteed's accused some of Newton's acolytes like Gregory and Halley to act like yes-man who complied with his humour, flattered him, and cried him up.[529] On the other hand, however, we should bear in mind that the master-disciple bond presupposed a reciprocal choice and a reciprocal commitment. Newton did not refuse the allegiance of his would-be acolytes and, on many occasions, returned their loyalty with patronage and friendship.

In the last decades, the network of people surrounding the English mathematician from the 1670s onward has been object of several studies; none of them, nevertheless, provides a unified and clear picture of the circle of intellectuals constituting the driving force of Newton's enterprise. My work does not accomplish entirely the task. Rather, it represents the starting point to cast light on this topic. In this sense, the concept of discipleship helps to identify those people that, among others, established with the English mathematician a close, personal, and trustworthy relationship. This aspect transpires not only from their work in support of Newton's project but also – and especially – from the language that they employed and the emotions that they expressed in their missives to the master. Newton – like Copernicus, Kepler and Galileo before him – treasured the

[529] The draft preface of Flamsteed's *Historia Cœlestis Britannica* (published posthumously in 1725) can be consulted on the Newton's Project: https://www.newtonproject.ox.ac.uk/view/texts/normalized/OTHE00033

precious help of talented and trusted disciples and nourished the value of an institution that, in different forms and with different purposes, maintained its importance over the centuries.

CONCLUSION

In 1677, the German mathematician Johann Christoph Kohlhans published the treatise *Neu erfundene Mathematische und Optische Curiositäten* in which he provided a detailed description of his latest research on optical techniques and the improvement of scientific instruments. In his work, the author made a curious choice of language; the text, indeed, presented a combination of foreign idioms, which included Arabic, Hebrew, Greek, Latin, and Syrian. In the first pages of the book, Kohlhans justified his unusual choice and explained that although publishing represented for him a religious obligation, he had nonetheless decided to disclose his *secreta optica* to a learned and circumscribed readership.[530] Only a few mathematicians were skilled enough to understand his optical theories and to replicate his scientific instruments and even fewer were able to decipher the panoply of foreign languages that he had used to write his work.

Kohlhans's case speaks loudly about the contrast between hiding and revealing that characterized the divulgation of scientific knowledge during the early modern age.[531] On the one hand, the mathematization of natural philosophy had rendered scientific claims and astronomical theories increasingly technical and difficult to digest. On the other hand, the advent of print publications and erudite journals had facilitated the circulation of findings and theories and had promoted their divulgation to a wider audience. This material infrastructure underpinned the transformation of values and practices connected to both the development and the dissemination of scientific knowledge. Alongside these changes, the emergence of a specific kind and structure of discipleship served as an appropriate and even necessary institution for educating skilled mathematicians and for connecting them and their masters – the community of experts – with a non-specialist readership.

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[530] J. C. Kohlhans, *Neu erfundene Mathematische und Optische Curiositäten* (Leipzig: Friederich Lankisch, 1677), p. 28.

[531] K. Vermeir, "Openness versus secrecy? Historical and historiographical remarks", *BJHS*, June 2012, Vol. 45, No. 2, Special Issue: States of Secrecy, pp. 165-188. W. Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton university press, 1994).

My analysis of the relationship between Copernicus and Rheticus reveals why a new type of discipleship emerged at the same time as *De Revolutionibus* was published. When Rheticus arrived in Frauenberg in 1538 he had already received a solid education in mathematics. Still, the close and personal interaction he enjoyed with the Polish astronomer prepared him to master the mathematical technicalities underlying the heliocentric theory and, more importantly, allowed him to understand – and accept – the revolutionary idea that his master was proposing. As Westman pointed out, indeed, Copernicus's work presented a new theory that embodied or promoted a new disciplinary role for the technically-accomplished astronomer. The mathematical constructions contained in his work were not more difficult or technically recondite than previous astronomical work; instead, those standard techniques were marshalled to support a new and counter-intuitive physical theory of the heavens.[532]

Rheticus proved to be ready to accept the challenge and played a crucial role in both the publication and circulation of *De Revolutionibus*. On the other hand, it was only after engaging with Rheticus that Copernicus overcame his notorious and – one might say – Pythagorean reluctance toward publication and entrusted his disciple with the circulation of his astronomical work. The importance of this case cannot be overestimated: the complex events that led to the publication of *De Revolutionibus* illustrate not only the transition from a circumscribed transmission to a wider – though still controlled – circulation of highly technical mathematical knowledge; they also emphasize the crucial role that a master-disciple relationship played in this process. Maybe, without Rheticus the development and reception of the heliocentric system would have taken on a very different form.

In the following decades, the interaction between the Polish astronomer and his disciple Rheticus became an exemplary model for the transmission of varieties of the "new philosophy". During the 17th century, like Copernicus, early modern astronomers, mathematicians, and natural

[532] R. Westman, "The Astronomer's role".

philosophers believed that the radically novel, counter-intuitive, and technically difficult aspects of their theories rendered their findings inaccessible to non-experts; most of them nonetheless became increasingly inclined to cultivate disciples and assign them the task of disseminating scientific knowledge. The span of time and the variety of contexts considered in this work emphasize this aspect. The differences between each case nonetheless highlight the flexible nature of this institution and the variety of forms and nuances that it could assume in different circumstances.

Kepler's case is the most emblematic in this sense: the relationship that the German mathematician established with Michael Maestlin reflected the traditional version of the master-disciple relationship within the institutional context. However, Kepler himself never accepted the strict institutional obligations imposed by the university and hence as a master operated quite unconventionally. Like Tycho, he worked mostly outside the academic context, in a setting where the family and social structures were much more relevant to his scientific enterprise. Still different was the nature of Galileo and Newton's cultivation of disciples. The former developed a systematized procedure for gathering disciples – most of whom had come from, and indeed remained in an ecclesiastical environment. On the other hand, the latter cultivated acolytes at various stages of his scientific enterprise and assigned them with different tasks according to their expertise. Besides the dissemination of knowledge, indeed, the disciples contributed in different ways to the accomplishment of their master's scientific programs. After becoming part of the inner circle, the disciples became critical pieces of complex networks that, in a century and a half, enriched and guided new views of the universe.

It is important to stress once again that the choice of the word "disciple" is not accidental. One of the main purposes of my project, indeed, consists in delineating the boundaries between this term and other expressions like "pupil" or "follower", which often have been indistinctly used as synonyms by the historiography. In this sense, my work pays attention to the nuances of the actors' categories, as well as to the social structures associated with them. In the early modern context, discipleship entailed elements such as trust, absolute commitment, and personal contact that

distinguished this special bond from other kinds of social connections. A disciple was someone who learnt from a master and modelled his intellectual life after him. The alignment with a specific "circle" had important implications – most of the time its members espoused *tout court* the master's views, but it did not imply the loss of the disciple's own intellectual property. On the contrary, each acolyte was chosen for his outstanding talent and trained – directly or not – to achieve a level of competence that, most of the time, surpassed the master's skilfulness.

In this context, the close link between discipleship and patronage deserves a different consideration. In the early modern period, patronage represented a major factor – occasionally the decisive factor – to establish hierarchical and vertical relationships between individuals or networks of individuals. This practice represented an essential element of early modern scientific production and played a crucial role also in the master-disciple relationship. Before meeting their masters, most of the acolytes considered in this work were young mathematicians in search of an institutional affiliation; on the other hand, when they began to cultivate disciples, Copernicus, Kepler, Galileo, and Newton were prominent figures with the power to endorse their pupils' careers, the authority to recommend them for prestigious positions, and the need to have trusted allies within the academic context of the time. The statements and actions of both masters and disciples, besides, did not differ greatly from those of patrons and clients respectively. This parallelism provides food for thought and opens to new studies that, by analysing patronage in relation to discipleship, might shed further light on the development of these two institutions.

Another important topic that is worthy of further investigation concerns the prevalence of male figures in traditionally male-centric social settings and, in contrast, the seeming absence of women in the context of early modern discipleship.[533] On the one hand, the concept of homosociality – a term that describes social bonds between persons of the same sex – might help to explain the establishment of social bonds created to maintain and defend hegemony and might

[533] N. Zack, *Bachelors of Science. Seventeenth Century Identity, Then and Now* (Philadelphia: Temple University Press, 1996) pp. 154-167.

allow understanding the emotional closeness and intimacy that often characterized the master-disciple relationship as a form of friendship.[534] On the other hand, it would be interesting to investigate how and why women came to be excluded from the main narrative despite their deep involvement in various aspects of the scientific practice of their time. What was specifically masculine about the homosociality involved in the often intense and intimate settings in which masters and students found themselves? Did females ever function as disciples as part of a much more general category of support personnel?

The history of science has been notably slow to consider the participation of women in the development of early modern science. Only by the twenty-first century, scholars in this field have begun to address the gender issue, opening to a more nuanced and critical approach that integrates the possible role of female figures in their analysis. Several studies have shown that during the early modern age women not only participated actively in the intellectual debates of their time; they were also deeply involved in the empirical and theoretical practices connected to the production of scientific knowledge. Among these women, it is important to mention Sophia Brahe,[535] Margherita Sarrocchi,[536] Maria Cunitz,[537] and Maria Winkelmann-Kirch.[538] Their fundamental role in the development of scientific knowledge has been widely acknowledged; still, little is known about the

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[534] On this topic, see the analysis of Newton's celibacy in R. Iliffe, *Priest of Nature*, pp. 176, 182,183.

[535] Sophia Brahe was a Danish noblewoman and sister of the astronomer Tycho Brahe. She was a frequent visitor at Uraniborg where she assisted her brother with astronomical observations associated with his publication *De nova stella* (1573). J. Christianson, *On Tycho's Island: Tycho Brahe and His Assistants, 1570-1601*(Cambridge, 2000), pp. 258-264.

[536] Margherita Sarrocchi was an Italian poetess and a fervent supporter of Galileo's astronomical theories. Her skills in astronomy, geometry, and physics were much appreciated by the intellectual community of the time, so much so that after the publication of Galileo's *Sidereus Nuncius* (1610), she was consulted by the Studio of Perugia to validate Galileo's discovery of Jupiter's satellites. M. Ray, *Daughters of Alchemy: Women and Scientific Culture in Early Modern Italy* (Harvard, 2015), pp. 111-155.

[537] Often defined by the historiography as the "Second Hypatia", Maria Cunitz was was widely known for her deep interest in astronomy and for her skillfulness in mathematics. Her work *Urania propitia* (1650) testifies to her expertise: the treatise provided new tables, new calculational methods, and a more simple and direct solution to what is known as "Kepler's Problem". During her life, she corresponded with the major astronomers of the time like Pierre Gassendi, Ismaël Boulliau, and Johannes Hevelius. M. Ogilvie, J. Harvey (eds.), *The Biographical Dictionary of Women in Science: Pioneering Lives from Ancient Times to the Mid-20th Century* (London: Routledge, 2000), pp. 629-30.

[538] Maria Winkelmann-Kirch was a German astronomer. The wedding with Gottfried Kirch boosted her interest in astronomy and mathematics and offered her the possibility to work alongside her husband. Maria, indeed, worked as Gottfried's unofficial – but recognised – assistant: together they made observations and performed calculations to produce calendars and ephemerides. G. Bernardi, *The Unforgotten Sisters: Female Astronomers and Scientists before Caroline Herschel* (New York: Springer, 2016), pp. 83-6.

process that allowed all of them to enter – officially or not – the scientific community of their time. How did a woman get an education in the scientific disciplines at a time when women were not allowed to attend universities and academies? How was their talent recognized and who provided them with training? The answer to these questions largely lies in the changing social and institutional frameworks within which science was practised during the early modern age. Studying the different trajectories followed by a woman to get an education in the scientific disciplines would be essential to provide a comprehensive account of the production of scientific knowledge during the early modern age. In this sense, my work is programmatic and propaedeutic and represents just the beginning of a research programme that I hope to explore further in the next years.

The role of women in the early modern scientific enterprise and, specifically, in the context of discipleship, would assume even more value if considered in relation to other fields of study: the case of the early modern Italian painter Artemisia Gentileschi – the first woman admitted into the Accademia delle Arti e del Disegno in Florence – for example, provides interesting cues to understand the dynamics that allowed a woman to get an education and to be integrated into the intellectual community of the time. In this sense, the purpose of my project goes beyond the boundaries of the history of science and aims at understanding to what extent these chains of transmission drew from and differed from contemporary and pre-existing pedagogical forms. Developing a novel treatment on how and why highly technical knowledge was passed on from a master to his – male and female – disciples in different areas would broaden the extent and the significance of my research and would inform more general histories of the early modern world.

During the last decades, historians have devoted surprisingly little attention to the nature, structure, and evolution of discipleship in the context of early modern science. At the turn of the 16th and 17th century, disciples played a crucial role in the arena of heliocentrism, and they were likewise essential in the following decades for the establishment of new astronomical, mathematical, and philosophical theories. They constituted the heart of a quasi-religious movement whose core doctrines needed to be proselytised; the Word needed to be spread throughout the

world, and the disciples were necessary for the task. It is time to recognize the essential role that this institution played in the early modern age, not only to acknowledge the disciples' contribution to their master's success but also to enhance the extraordinary work of young mathematicians that, on many occasions, outstripped their masters' talent. Ultimately, indeed, this analysis wants to overcome a historiography based on the great protagonists (and their great ideas) which produces a linear and cumulative narrative, to focus instead on the complex living fabric that gave birth to mathematized natural philosophy in the early modern period.