TRACES OF AN INVISIBLE GIANT: SHARED KNOWLEDGE IN GALILEO'S UNPUBLISHED TREATISES

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This paper discusses Galileo's unpublished treatises related to his theory of motion of which we find many traces in his extant manuscripts such as his notes on motion, manuscript 72 of the Galilean collection in Florence. It may thus seem as if this paper focuses on an aspect of the emergence of classical mechanics which is relevant only for those specialists interested in the biographical origins of Galileo's contributions. We shall argue, however, that a study of unpublished manuscripts from the perspective of a historical epistemology reveals structures of the development of scientific knowledge which tend to be obscured by focusing, as it is common, only on published writings. Such focusing on published writings is, in fact, inherent in interpreting the development of scientific knowledge as resulting from individual contributions that become effective only through publications.

The common concentration on published works is based on two precarious assumptions that will be challenged in the following.

- First, it is usually assumed that the progress of scientific knowledge, in particular the emergence of classical mechanics, is essentially determined by a sequence of events starting with individual discoveries, disseminated by publications, and finally evaluated by the reception of the scientific community.
- Second, it is usually assumed that it were specifically Galileo's publications that represent the birth of the classical theory of motion, essentially unburdening himself of the millenary tradition of a mistaken natural philosophy.

We do not question the facts which can be put forward in order to justify such assumptions, but the rationale of the argument itself.

The invisible hand of shared knowledge

We will illustrate historical circumstances which may raise doubts whether such assumptions can be considered as a sound base of historical research by a thought experiment. Let us hypothetically assume that a scholar contemporary to Galileo pursued experiments with falling bodies and discovered the law of fall as well as the parabolic shape of the projectile trajectory, that he found the law of the inclined plane, directed the newly invented telescope to the heavens and discovered the mountains on the moon, observed the moons of the planet Jupiter and the sunspots, that he calculated the orbits of heavenly bodies using methods and data of Kepler with whom he corresponded, and that he composed extensive notes dealing with all these issues. In short, let us assume that this man made essentially the same discoveries as Galileo and did his research in precisely the same way with only one qualification: he never in his life published a single line of it. Would we deny him credit for any contribution to the history of science just because he did not influence the scientific community with any publication? Would we consider such parallelism of developments as insignificant on account of one of the two scholars not influencing the alleged normal chain of events from discovery, via publication to reception?

As a matter of fact, the above description refers to a real person, Thomas Harriot, whose work closely resembles that of Galileo.[1] But how can the striking parallelism between the two scientists be explained? Was there perhaps a secret "influence" which has so far escaped the scrutiny of historians, or is there any other explanation? From the usual perspective, the development of scientific knowledge is considered to be a process involving individual ideas, their reception by a community, and the effect of the ideas of one individual on the other in terms of so-called "influences". We will argue, on the other hand, that the often striking similarities in the work of Galileo and his contemporaries can be explained by common structures of knowledge, common challenges, and a similar social environment conditioning the communication of scientific information, rather than by the exchange of ideas embodied in publications.

This becomes particularly evident in the fate of Galileo's unpublished writings. It turns out that, in many cases, his writings remained unpublished not so much because he failed to succeed in completing his ambitious projects of publication, but for other reasons. We argue that these projects were, in fact, overturned by the development of shared knowledge. To use

[1] See Shirley, J. W., 1983.

concepts introduced by Yehuda Elkana, these projects were either superseded by the dynamics of bodies of knowledge which Galileo shared with his contemporaries, or they were hampered by images of knowledge, that is, by ideas about knowledge that are particularly susceptible to political as well as biographical circumstances.[2] Indeed, the development of knowledge proceeded then, as it does today, at a different pace from that of the production of publications.

Galileo's unpublished writings

Among the oldest unpublished writings of Galileo, a treatise on a hydrostatic balance has been preserved, entitled *La bilancetta* dating from 1586.[3] A treatise on centers of gravity, entitled *Theoremata circa centrum gravitatis solidorum* from 1587 originally also remained unpublished and was only added as an appendix to the *Discorsi* published half a century later.[4] These treatises show him –like contemporaries such as Guidobaldo del Monte– as an avid follower of Archimedes who had not only assiduously acquired the mathematical techniques of Archimedean mechanics but also shared the Archimedean interest in its practical applications.

When appointed as a professor at the university of Pisa in 1589 Galileo followed an entirely different path.[5] Probably from this time, several unpublished treatises dealing with questions of Aristotle's natural philosophy and logic are preserved, among them treatises entitled *De mundo*, *De caelo*, *De elementis,* and *De demonstratione*.[6] Had these treatises been published they would have shown Galileo as a typical philosopher of his time, diligently studying and disseminating the doctrines of contemporary Aristotelian natural philosophy, and not as the creator of a new science of motion.

Probably the most well known unpublished treatise of Galileo is his manuscript *De motu antiquiora* from around 1590.[7] Actually the manuscript bundle thus labelled comprises several more or less complete versions and notes for even more treatises. They document that he shared the anti-Aristotelian ambitions of many of his contemporaries and that he, just as Benedetti or Guidobaldo before him, grasped the opportunity to revise Aristotle's theory of motion by reformulating it as a theory of motion in media with the help of Archimedean hydrostatics.[8]

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[2] See Elkana, Y., 1988.

[3] See Galilei, G., 1890-1909, I: 215ff.

[4] See Galilei, G., 1890-1909, I: 187ff. and Galilei, G., 1890-1909, VIII: 313.

[5] See Wohlwill, E., 1909-1926 and Drake, S., 1978.

[6] See Galilei, G., 1890-1909, I: 22-177, Wallace, A. W., 1992, and Wallace, W. A., 1977.

[7] See Galilei, G., 1890-1909, I: 243-419, Fredette, R., 1969, Giusti, E., 1998, and the contribution by Raymond Fredette to this volume.

[8] See Benedetti, G. B., 1585, and del Monte, G., ca. 1587-1592, p. 41.

After his move to Padua in 1592, Galileo, aside from his duties as a professor, engaged in quite different activities such as giving private lessons and advising the Venetian republic on technical matters.[9] Such activities were typical of an engineer-scientist of that time. In the context of these activities he wrote or planned several treatises that remained mostly unpublished but circulated among his contemporaries, two treatises on fortification, a treatise on mechanics, entitled *Le meccaniche*, several versions of the manual for the use of his military compass, eventually published only in view of a priority dispute, and finally a treatise on the sphere, entitled *Trattato della sfera ovvero cosmografia*.[10]

The contemporary discussion on Copernicanism confronted Galileo with various occasions to express his changing views on the subject in writings that remained largely unpublished. These writings ranged from anticopernican side-remarks in his treatise on the sphere, via refutations of anticopernican arguments of philosopher colleagues starting as early as 1597, to planned or actually written treatises on mechanical arguments interpreted as evidence in favour of the Copernican system.[11] Among these arguments is an attempt to explain the tides along the model of a swinging pendulum, an attempt which is documented by manuscripts comprising notes dating back as early as the 1590s,[12] and also an unpublished treatise of 1616, entitled *Discorso del flusso e reflusso del mare*.[13] An attempt to explain the constitution of the planetary system along the model of projectile motion is documented by notes dating from around 1604.[14] In general, most of Galileo's early treatises on Copernican issues remained unpublished or were merely circulated in the form of letters.

Manuscripts and correspondence show that in the period of his most intense work on problems of motion around 1602, Galileo focused on two key problems of potentially high practical impact, ballistics and the pendulum. Evidently he planned to dedicate treatises to these subjects, which, in spite of the tremendous work invested in them, remained unwritten.[15] Several years later in 1610, he claimed to have almost completed a number of treatises, among them three books offering an entirely new theory of motion which, however, probably did not exist or, at least, remained unpublished.[16]

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9 See the contribution by Matteo Valleriani to this volume.

10 See Galilei, G., 1890-1909, II: 7-191, 203-253, 335-510.

11 See Galilei, G., 1890-1909, II: 193-202, 203-253.

12 See Galilei, G., ca. 1602-ca. 1637, folio 154 recto. Galileo's idea of a tidal theory is also documented in notes from the year 1595 that are found in a notebook of Paolo Sarpi; see Sarpi, P., 1996, 424-427, notes number 569, 570 and 571; see also the discussion in Renn, J., et al., 2000.

13 See Galilei, G., 1890-1909, V: 371-395.

14 See Galilei, G., ca. 1602-ca. 1637, folios 134, 135 and 146.

15 See Hill, D. K., 1994.

16 See the letter to Belisario Vinta, May 7, 1610, Galilei, G., 1890-1909, X: 348-353.

In his position as a philosopher and mathematician at the Medici Court, which he took on in 1610, Galileo produced numerous scientific writings not intended for publication. Several of these unpublished writings contain expositions of Galileo's scientific achievements in the context and for the purpose of technical applications.[17] A Galilean treatise has been preserved as an appendix to a diplomatic note written in 1612 by the Grand Duke to the government of Spain concerning free Tuscan access to the East Indies as well as the West Indies.[18] It describes a method for determining longitude on the basis of Galileo's observations of the Jupiter satellites. With several unpublished writings on hydraulics, among them a lengthy expertise on the regulation of the river Bisenzio written in 1630, Galileo fulfilled his function as an expert advisor to the Tuscan government.[19]

Galileo's conclusive work of 1638, the *Discorsi*, actually comprises only a fraction of his writings on motion and mechanics. While books on motion such as the one he had promised in 1610 were actually included in the form of fictive treatises, several other planned or written treatises dealing with subjects such as percussion or the hanging chain remained unpublished. In spite of unceasing attempts to cover all of this material in his definitive publication by adding ever new chapters to it, the *Discorsi* themselves were eventually published merely as a torso.[20]

The heritage of shared knowledge

Even this brief survey of Galileo's unpublished treatises makes it more evident than his few strategically placed publications that his work was conditioned by an array of transmitted knowledge systems which he shared with his contemporaries. These systems in turn were constrained by controversial interpretations of their social status and their cultural meaning. The most obvious case is represented by the controversial cosmological models developed in the context of the millenary tradition of astronomy, that is, the Ptolemaic, the Tychonic, and the Copernican models of the mechanism of planetary motion. To come to another body of knowledge, Galileo's deductive theory of motion was evidently not unrelated to mechanics. It was, however, not an immediate continuation of the tradition of deductive mechanical treatises. It rather copied the *Archimedean* model of constructing deductive theories of physical phenomena. Both approaches were in any case shaped by the tradition of mathematical theory. Obviously the mathematical tradition going back to antiquity did not only pro-

[17] See e.g., Galilei, G., 1890-1909, VIII: 571-587.
[18] See Galilei, G., 1890-1909, V: 415-425.
[19] See Galilei, G., 1890-1909, VI: 627-647.
[20] See Renn, J., et al., 2000.

vide Galileo's theory of motion with a model for its deductive form but also with its most powerful instrument of the mathematical analysis of space, Euclidean geometry. Furthermore, Galileo's new science of motion shared its subject with the dominating doctrines of the natural philosophy of the time, rooted in the ancient tradition of Aristotelian physics, elaborated, questioned, and in various ways revised by generations of commentators of medieval scholastic Aristotelianism. Last but not least, let us stress the significance of a further body of knowledge. Most important but often overlooked is the fact that Galileo's theory of motion draws heavily on the knowledge accumulated in the handicraft and engineering tradition which reaches even further back in history than any theoretical reflection on it.[21]

The heritage thus only briefly outlined did obviously not consist of one homogenous body of knowledge but rather of diverse strands of theoretical traditions based on partly incompatible foundations whose mutual relations represented one of the intellectual challenges of the time. This conflict-laden heritage was the basis for any conceptualisation of motion in the early modern period and, at the same time, provided numerous obstacles against modifications endeavoured in order to meet new challenges.

In the following, we will discuss several examples of shared knowledge. They are taken from Galileo's unpublished treatises. From the point of view of historical epistemology we will analyse how the emergence and dissemination of his science of motion grew out of the shared knowledge of the time.

Example 1: Intuitive physics and Aristotelianism

We first turn to Galileo's relation to Aristotelian physics as it becomes particularly evident in the light of his unpublished treatises. It is a common characteristic of Galileo and his contemporaries that their attitude towards Aristotelian physics was anything but simple. Based on their familiarity with Galileo's publications only, mid-nineteenth century historians of science have coined an image of Galileo which characterizes him, in contrast to contemporary philosophers, as an ardent defender of experience against Aristotelian dogmatism. When Favaro published most of Galileo's extant treatises it became clear that this image of Galileo was untenable. Nevertheless this image was never in principle revised. Even today the fact that the young Galileo composed a number of Aristotelian treatises is often considered as merely the excusable lapse of an immature scientist. From our viewpoint, however, Galileo's unpublished treatises suggest that there is no principal difference between the attitudes of Galileo and of his contemporaries towards Aristotle. In fact they provide a context for his published writings which makes clear that Galileo shared with his contemporaries the

[21] See Renn, J., et al., in preparation.

adherence to essential assets of Aristotelian physics and that he did so for good reasons.

As a matter of fact certain types of physical knowledge predate any systematic theoretical treatment. The most basic knowledge presupposed by physics is based on experiences acquired almost universally in any culture by human activities such as moving one's body around or handling objects under normal conditions characteristic of our natural environment on earth.

Although the fundamental notions of such physical knowledge are closely related to concepts of classical mechanics, they do not correspond to its basic categories. Most of them turn out to rather resemble the basic assumptions of Aristotelian physics, including its medieval elaboration, as well as its early modern critique. Solid bodies usually need a force to be moved. This force depends on the amount of motion to be produced; stronger forces can move greater bodies and cause a greater motion. Once bodies are moving they have acquired a certain impetus that makes them continue to move for some time before they come to rest. A moving body can itself exert a force on objects which resist its motion. In order to stop a moving body, some counteracting force is required depending on the size of the body and the vividness of the motion. All such experiences together constitute a sufficiently reliable basis for the prediction of the behaviour of bodies which are subjected to human activities in practical contexts, forming a system of knowledge and beliefs that may be called, adopting a term from cognitive psychology, "intuitive physics".

Any attempt to create a theory of nature as general as Aristotelian physics has to start from this basic body of knowledge, even if its goal is to revise the Aristotelian system. This explains why Galileo, as has been pointed out already, in his early attempts to give a systematic account of the physical knowledge of his time in the same way as his contemporaries combined an anti-Aristotelian attitude with an adherence to basic Aristotelian assumptions. Such assumptions anchor, as we have extensively shown elsewhere, the conceptual framework even in what he considered a new science of motion in his definitive publication, the *Discorsi*.[22]

Example 2: Theoretical knowledge and scholasticism

A second strand of knowledge, not rooted in intuitive physics, was, nevertheless, also part of the shared knowledge of the time because it was transmitted as a canon of theoretical knowledge within the university tradition; it is represented by the sophisticated elaborations of Aristotelian physics in the medieval scholastic tradition. None of the assumptions of this theoreti-

[22] See Damerow, P., et al., 1992, also for the following.

cal tradition are as self-evident and irrefutable as the elements of Aristotelian theory rooted in intuitive physics. These assumptions were the issues of debates extending over centuries and were consequently the natural starting points for creating new theories of motion in early modern times.

Historians who attempt to understand the spreading of these new theories in seventeenth century Europe are confronted with a puzzle. The treatises and notebooks of this time, as they were written by natural philosophers such as Galileo, Descartes, Baliani, or Harriot, show a great variation with regard to the phenomena considered, the basic axioms, or the deductive organization. Nevertheless, these treatises also show a number of peculiar common features that cannot be explained by their shared starting point in the core assumptions of Aristotelian theory rooted in intuitive physics.

For instance, they all conceptualize the phenomenon of acceleration, which plays quite different roles in their individual versions of a new science, in terms of the same odd medieval concepts incompatible with classical physics. In particular, accelerated motion is understood as a quality that has an extension as well as an intension, characterized by changing degrees.

In order to understand this puzzling commonality one can either search for direct influences in individual biographies or search for general structures of knowledge at that time. When historians of science focus on Galileo's work and attempt to explain what they see as the sudden appearance of the key concept of changing "degrees of velocity" in the course his work on a science of motion, they usually search to identify the sources of this concept in specific influences occurring during his biography, for instance, in the form of books he must have read at a particular time. They have thus, for instance, long been irritated by the fact that the fourteenth century work of Oresme and of the Oxford calculatores, to which the notion of motion as a quality with changing degrees can be traced back, was essentially no longer read in the time of Galileo and could hence not figure as a possible source of his ideas on accelerated motion. When historians of science discuss the general state of ideas in the seventeenth century, they tend to portray medieval Aristotelian scholasticism merely as the counter position against which Galileo's theory of motion gained its profile as a new science, neglecting the potential of Aristotelianism as a generic knowledge resource available to Galileo and his contemporaries.

Galileo's unpublished commentaries on Aristotelian physics mentioned above make it not only amply clear that he had thoroughly appropriated the immense knowledge accumulated in the scholastic tradition of elaborating and commenting Aristotle, but also that he had thus acquired a resource of knowledge that provided essential assets of the new science of motion, assets such as the conceptualisation of acceleration in terms of the changing degrees of a quality. This conceptualisation was in fact part of the doctrine of intension and remission transmitted by the lively scholastic tradition of the time, a tradition from which contemporary intellectuals could hardly escape, whether they encountered it in the college of La Flèche, as was the case for Descartes, or in the lecture notes of Jesuit professors of the Collegio Romano, as was the case for Galileo.[23]

Example 3: Aristotelianism and Archimedean theory as coexisting bodies of knowledge

Let us turn to our third example of how shared knowledge resources created common framing conditions for Galileo and his contemporaries. This example serves to make evident that they drew on shared bodies of knowledge not only separately from each other by exploiting their individual potentials but also tried to merge incompatible knowledge structures into a new unity. A telling example for this type of theory construction is provided by the attempts of Galileo to combine the Aristotelian theory of motion with Archimedean theory of buoyancy within a deductive framework following the model of Euclid and Archimedes himself. Given that in Aristotelian theory motion is possible only as motion in a medium and that Archimedes gave a precise account of how the medium affects a body submerged in it, any study of the velocity of falling bodies had either to combine both theories in this point or to radically change basic assumptions of either of them. This explains why not only Galileo but also contemporaries such as Benedetti, Guidobaldo del Monte, Beeckman, or Harriot all advanced new theories of motion of fall different in detail but in agreement on this point.[24] In the case of Galileo we are able to trace the development of such a theory through various stages. He started out by writing a dialogue that gave him the occasion to cautiously revise the Aristotelian theory by introducing proponents holding different positions without identifying himself with one of them.[25] This attempt was followed by a more audacious treatment in the form of a scholastic treatise in which he promoted a radical critique of Aristotle but essentially stuck to Aristotelian assumptions.[26]

Finally he conceived the project of a new science of motion based on this theory and to be formulated following the model of a deductive treatment in the style of the succinct *De ponderoso e levi,* attributed to Euclid and familiar to Galileo. But he obviously did not realize this project since only an outline survived. The concise style of the planned treatise becomes evident even when considering only a few of the issues covered.[27]

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[23] For Descartes see Gaukroger, S., 1995, for Galileo see Wallace, W. A., 1981.

[24] See Benedetti, G. B., 1585, del Monte, G., ca. 1587-1592, p. 41, Beeckman, I., 1939 and, for Harriot, BL Add MS 6788 folios 144-148.

[25] See Galilei, G., 1890-1909, I: 367-408.

[26] See Galilei, G., 1890-1909, I: 247-340.

[27] See Galilei, G., 1890-1909, I: 418f.

Concerning the ratio of motions of the same mobiles in different media.
Concerning the ratio of the motions of different mobiles in the same medium.
Concerning the cause of the slowness and the speed of motion.

Example 4: Theoretical knowledge and mechanics

Our fourth example introduces yet another body of knowledge relevant to the development and reception of Galileo's science of motion. Besides the uninterrupted Aristotelian tradition one has to take into account that the sixteenth century saw the revival of another ancient tradition namely that of deductive treatises specifically devoted to mechanics. This revival was closely related to the growing practical importance of machine technology since the Renaissance. It was based on a small number of treatises from antiquity and the Middle Ages which use the lever as a mental model for interpreting mechanical phenomena.[28] Guidobaldo del Monte, under whose patronage Galileo achieved his positions in Pisa and later in Padua, published a comprehensive compilation of this knowledge thus creating the most influential mechanical treatise of his time.[29] Galileo's unpublished treatise on mechanics mentioned above which he composed after his move to the Venetian republic, the technological center of that time, similarly represents an appropriation of the ancient tradition of mechanics.[30] At that time Galileo had reoriented his interest from the critique of Aristotelian philosophy to the practical challenges of an engineer-scientist.

Galileo's unpublished treatise on mechanics is usually studied with the primary intention of finding something innovative. This search has even been successful to a certain extent. From the viewpoint of historical epistemology, however, this treatise deserves attention primarily for another reason. It represents the basic structures of mechanical knowledge which Galileo shared with his contemporaries, and which served them as a universal instrument for their theoretical interpretation of the rapidly developing contemporary machine technology.

Example 5: Practical knowledge and challenging objects

The opportunities and challenges offered by the new technology represent another shared knowledge area, whose character was, however, much more

[28] From Pseudo-Aristotle via Thabit ibn Qurra to Jordanus see Aristotle, 1980 and Clagett, M., et al., 1960.
[29] See del Monte, G., 1577 and del Monte, G., 1581.
[30] See Galilei, G., 1890-1909, II: 146-191.

diverse than that of the bodies of knowledge transmitted by ancient traditions. It does not come as a surprise that Galileo, once he had redirected his activities towards technical problems, became acquainted with technologies such as ballistics, shipbuilding, and fortification and that he prepared a couple of treatises which seem to have nothing to do with the great discoveries he is usually praised for. Precisely these treatises provide us with a key for understanding what type of knowledge triggered the transformation of ancient mechanics into the theory of motion of classical physics. Galileo's engagement with this type of knowledge becomes particularly clear in the cases of ballistics and of the pendulum. It was only his interest in ballistics which made Galileo realize the theoretical implications of an experiment on projectile motion which he performed years before, as we have shown elsewhere,[31] together with Guidobaldo del Monte. Similarly, as Viviani reports, the first reaction of Galileo after having discovered the isochronism of the pendulum was to explore its usefulness for a technical context, that is, for the construction of the pulsilogium for time measurement in medicine.[32]

In the case of ballistics it has to be pointed out that any theory of projectile motion advanced at that time had to take into account the common knowledge of the practitioners of ballistics as was transmitted not only by participation and oral transmission but also by numerous published as well as unpublished military treatises. The knowledge of the artillerists based on their professional experience included that the speed of a projectile increases with the force the exploding powder exerts on it, that more projectile weight requires more force to reach the same distance, that the distance of the shot depends on the angle, that there is an angle at which this distance reaches a maximum and that there are angles at which flat and steep shots reach the same distance though with different effects.[33] This type of knowledge also provided a starting point for early modern engineer-scientists such as Leonardo, Tartaglia, Aquilone, Puchner, Harriot and last but not least Galileo. Among his papers he left the outline of an unwritten treatise entitled *Particular privileges of the artillery with respect to the other mechanical instruments,* probably dating back to the early Paduan years.[34] It illustrates the role of reflection on practitioner's knowledge for the creation of a new theory of projectile motion by Galileo. Among the issues Galileo intended to deal with in his planned treatise are topics such as:

> If one operates with a greater force in a certain distance or from nearby.
> Which line the ball describes in its [course].
> ...

[31] See Renn, J., et al., 2000.

[32] See Viviani, Galilei, G., 1890-1909, XIX: 597-646 and Drake, S., 1978.

[33] See Büttner, J., et al., in preparation.

[34] See Galilei, G., ca. 1602-ca. 1637, folio 193 recto. An electronic representation of Galileo's notes on motion, is freely accessible from the website of the Max Planck Institute for the History of Science, ***http://www.mpiwg-berlin.mpg.de***.

> In which elevation you shoot farthest and why.
> That the ball in turning downwards in the vertical returns with the same forces and velocities as those with which it went up.

Given that such questions were at the center of interest for early modern engineers it could be only a matter of time before all such questions had been more or less sufficiently embedded into a coherent deductive theory of motion extending theoretical mechanics in the ancient tradition.

In the second case, the case of the pendulum, Galileo was confronted with a quite different type of challenging object. There is ample evidence that Galileo realized early in his Paduan period that theoretical mechanics as it was represented by Guidobaldo's and his own treatises was unable to explain even such trivial insights as its isochronism not to mention the puzzling parallelism between the law of fall and the dependence of the period of the pendulum on its length, the law of the pendulum. A whole bunch of manuscript pages show that Galileo desperately tried to derive the isochronism from traditional mechanics by approximating the circle described by the descending pendulum by a series of inclined planes with diminishing slope.[35] Galileo outlines the basic idea and describes the obstacles against its realization in the answer to a lost letter of Guidobaldo del Monte, who was obviously sceptical with regard to Galileo's attempts to use Aristotelian dynamics for understanding phenomena such as the swinging of the pendulum. He points out the difficulties posed by this particular challenging object:[36]

> Until now I have demonstrated without transgressing the terms of mechanics; but I cannot manage to demonstrate how the arcs [...] have been passed through in equal times and it is this that I am looking for.

When Galileo finally published his *Discorsi* he still lacked a satisfactory theory of the pendulum. Since he did not manage to include his results on the pendulum within the deductive framework of his theory of motion, he evidently saw no other solution for making these results public but to include them not within the fictive treatise presented in the *Discorsi* but to casually mention them in the dialogue parts.[37] He thus missed his last chance to place these results into the records of published discoveries, although the solution to this problem would have been only a small step within his theory.

[35] See Galilei, G., ca. 1602-ca. 1637, folio 166 recto and Hill, D. K., 1994.

[36] See the letter to Guidobaldo dal Monte, November 29, 1602, Galilei, G., 1890-1909, X: 97-100.

[37] For a treatment of the pendulum in the *Discorsi* see e.g., Galilei, G., 1890-1909, VIII: 139ff.

In fact, there is evidence that the story was not over yet. Shortly after Galileo's publication of the *Discorsi* Baliani also published a theory of motion which, however, turned the problem upside down.[38] Baliani used as an axiom the law of the pendulum already known to him and derived from it Galileo's law of fall. A hitherto unknown letter of Galileo to Baliani, a draft of which we identified among the notes of one of his disciples, contains a critique of Baliani's proof of the law of fall based on the law of the pendulum and proposes an improvement which, read in reverse direction, immediately gives a proof of the law of the pendulum in the framework of Galileo's own theory.[39] There can hence be no doubt that Galileo's theory of motion would have been able to include a theory of the pendulum if he had had the chance to compose it after he read the treatise of Baliani.

Example 6: Shared images of knowledge and the challenge of astronomy

Like mechanics, astronomy represents an ancient body of knowledge that received growing attention in the early modern period due to its increased practical significance, in particular in the context of the challenges for navigation posed by the discovery of new parts of the globe. At the same time, astronomical knowledge was tidily interwoven with the dominating worldview embraced by the Church which comprised the geocentric cosmology of Aristotle and Ptolemy.

Since the nineteenth century, the clash between this worldview and Galileo's defence of Copernicanism has repeatedly been interpreted as Galileo's systematic battle against an ancient dogma in order to defend his new science of motion. But as Galileo's unpublished treatises dealing with astronomical issues amply illustrate, his encounters with Copernicanism were neither rooted in a strategically planned battle nor were they the consequence of a conversion experience that made him a firm believer in the new world system. From the viewpoint of historical epistemology, they rather appear as the results of unavoidable encounters of an engineer-scientist with the shared knowledge of his time. These encounters gave Galileo, as was the case with his contemporaries, occasion to react to this knowledge in ways that were determined both by local contexts and by the dominating image of astronomical knowledge as an underpinning of the ruling worldview.

When Galileo wrote, for instance, his unpublished treatise on the sphere in the context of his teaching activities, he did not even bother to discuss the

[38] See Baliani, G. B., 1638 and the revised and substantially extended edition Baliani, G. B., 1646.

[39] Ms. Gal. 74, folio 35 verso ff. Galileo intended to publish this proof in the second edition of the *Discorsi* as can be inferred from a hand written marginal note in his copy of the first edition. See Galilei, G., after 1638, folio 62 recto (page 79 in the printed first edition).

Copernican system.[40] He even included a defence of the geocentric world system by physical arguments although he declared himself to Kepler in a letter of 1597 as a supporter of the new astronomical system.[41] Again, he gave, at the university of Padua soon after, a course on the geocentric world system based on his treatise on the sphere.[42] Nevertheless, he could not resist proving a philosopher colleague wrong when the latter criticized the Copernican system with unsound arguments. It was this academic rivalry that occasioned Galileo's first treatise on Copernicanism, circulated only in the form of a letter.[43]

However, the omnipresence of Aristotelian natural philosophy did not only account for the fact that engineer-scientists of the time almost unavoidably encountered related astronomical issues. Rather its embedding within the dominating worldview created boundary conditions that no attempt at a new science of motion at this time could ignore. In particular, the fact that in Aristotelian natural philosophy terrestrial physics was an integral part of a global world view enforced a cosmological meaning on every mechanical model of astronomical phenomena. This is true, for instance, for an attempt by Galileo that we have been able to reconstruct from his manuscripts. In fact, he tried to explain the tides by using the swinging pendulum as a mental model of the motion of the sea and by scaling-up the relation between the length of the pendulum and its period to the dimensions of the diameter of the earth in order to determine the period of the tides.[44] This is true also for his attempt to explain the periods of the planets in their orbits around the sun taken from Kepler's publication by using projectile motion as a mental model of the divine creation of the planetary system and by scaling-up his experiments with free falling bodies deflected into the horizontal to cosmic dimensions.[45] Although both attempts failed to match the observed data, he published these ideas in the *Dialogue* and in the *Discorsi*, not, however, as the systematic treatises he probably had hoped to write originally but as grand visions supporting the Copernican system, leaving out the details we know from his unpublished manuscripts.[46]

Example 7: Patronage and the shared social structures of knowledge

The last example of unpublished treatises discussed here is again of a quite different nature and points to a framing condition of the development and reception of scientific knowledge in this period that has been studied under the

[40] See Galilei, G., 1890-1909, II: 203-255.

[41] See the letter to Johannes Kepler, August 4, 1597, Galilei, G., 1890-1909, X: 67f.

[42] See Galilei, G., 1890-1909, XIX: 120.

[43] See the letter to Jacopo Mazzoni, May 30, 1597, Galilei, G., 1890-1909, II: 193-202.

[44] See Galilei, G., ca. 1602-ca. 1637, folio 154 recto.

[45] See Galilei, G., ca. 1602-ca. 1637, folios 134,135 and 146. For a detailed account of Galileo's cosmogony see the contribution by Jochen Büttner in this volume.

[46] See Galilei, G., 1890-1909, VII: 44f., 53f. and Galilei, G., 1890-1909, VIII: 283ff.

heading "Galileo Courtier".[47] At the end of 1630, Galileo completed an expertise that he had written by request of the Tuscan government. It represents an unpublished treatise on the regulation of the Bisenzio river in which Galileo mustered almost the entire arsenal of his science of motion to cope with a technological challenge of his time.[48] The writings he composed as a courtier under the patronage of the Medici family make it clear that the creation and dissemination of scientific knowledge in the early modern period is profoundly shaped by a social organization quite different from later periods. Gestures such as the appeal to the authority of princes, in exchange for gifts, here take the role of scientific credentials obtained by the recognition of peers.

For instance, when Galileo negotiated for his position at the Florentine court, he felt pressed to pretend that he could offer a cornucopia of unpublished treatises which in fact can only partly be identified among his manuscripts, probably because much of what he announced was actually never written:

> I also have some minor works on natural topics, like *De sono et voce*, *De visu et coloribus*, *De maris estu*, *De compositione continui*, *De animalium motibus*, and still others. I have also the intention to write some books concerning the soldier, educating him not only in abstract, but by teaching [him] by means of very good rules, all what is convenient to know and depends on Mathematics, like knowledge of castrametations, regulations, fortifications, assaults and captures, taking plants away, measuring with the sight, knowledge concerning artilleries, uses of various instruments, etc.[49]

However, it would mean to greatly underestimate the role of this social organization for early modern science if its impact is only considered with regard to the images of science on which the appreciation of scientific achievements by the ruling classes was based. Galileo's writings on hydraulics, such as his unpublished treatise on the regulation of the Bisenzio river show, that the social context of the early modern engineer-scientists provided in fact the precondition for the merging of bodies of knowledge such as practitioners knowledge about hydraulic engineering and scholastic theories on the dynamics of moving bodies whose traditions had been separated over centuries by a gulf of social status.

The irresistible spread of shared knowledge

Let us end as we began with a thought experiment. Let us assume that an early modern scientist had made an important discovery such as, for

[47] See Biagioli, M., 1993.
[48] See Galilei, G., 1890-1909, VI: 627-647.
[49] See the letter to BelisarioVinta, May 7, 1610, Galilei, G., 1890-1909, X: 348-353.

instance, the parabolic shape of the projectile trajectory, but that he hesitated to publish it because he consciously attempted to hide his discovery hoping to eventually make a fortune from it. Would it simply be possible to hide it or would it have been rediscovered by someone else or spread in spite of attempts to conceal it? As long as we conceive of the dissemination of scientific knowledge in terms of a chain of discoveries, their subsequent publication, and finally their reception, both events seem to be extremely unlikely. Once again, our thought experiment turns out to correspond to a real story that makes it possible to actually verify the outcome. It is the story of Galileo's failed attempt to hide the discovery of the parabolic trajectory for more than forty years.

When Bonaventura Cavalieri in 1632, shortly after the publication of Galileo's *Dialogo*, published his book *Lo Specchio Ustorio overo Trattato delle Settioni Coniche* on parabolic mirrors, he sent Galileo a letter which contains the following information:[50]

> I have briefly touched the motion of projected bodies by showing that if the resistance of the air is excluded it must take place along a parabola, provided that your principle of the motion of heavy bodies is assumed that their acceleration corresponds to the increase of the odd numbers as they follow each other from one onwards. I declare, however, that I have learned in great parts from you what I touch upon in this matter, at the same time advancing myself a derivation of that principle.

This announcement shocked Galileo. In a letter written immediately afterwards to Cesare Marsili, a common friend who lived like Cavalieri in Bologna, he complained:[51]

> I have letters from Father Fra Buonaventura with the news that he had recently given to print a treatise on the burning mirror in which, as he says, he has introduced on an appropriate occasion the theorem and the proof concerning the trajectory of projected bodies in which he explains that it is a parabolic curve. I cannot hide from you, my dear Sir, that this news was anything but pleasant to me because I see how the first fruits of a study of mine of more than forty years, imparted largely in confidence to the said Father, should now be wrenched from me, and how the flower shall now be broken from the glory which I hoped to gain from such long-lasting efforts, since truly what first moved me to speculate about motion was my intention of finding this path which, although once found is not very hard to demonstrate, still I, who discovered it, know how much labour I spent in finding that conclusion.

[50] Bonaventura Cavalieri to Galileo, August 31, 1632, Galilei, G., 1890-1909, XIV: 378.
[51] Galileo to Cesare Marsili, September 11, 1632, Galilei, G., 1890-1909, XIV: 386.

Galileo received an immediate answer from Cavalieri.[52]

> I add that I truly thought that you had already somewhere written about it, as I have not been in the lucky situation to have seen all your works, and it has encouraged my belief that I realized how much and how long this doctrine has been circulated already, because Oddi has told me already ten years ago that you have performed experiments about that matter together with Sig.r Guidobaldo del Monte, and that also has made me imprudent so that I have not written you earlier about it, since I believed, in fact, that you do in no way bother about it but would rather be content that one of your disciples would show himself on such a favourable occasion as an adept of your doctrine of which he confesses to have learned it from you.

He offered all kinds of options for a reconciliation and even proposed that he would finally

> ... burn all copies so that with them the reason is destroyed for which it is possible that I have given disgust to my master Galileo so that he could say like Cesar to me "tu quoque, Brute fili".

In short: At a time when Galileo's collaborators were using and spreading the knowledge of Galileo's discovery, convincing themselves that it must have been long published, Galileo himself still fought like a Don Quijote to keep it secret.

To sum up: Galileo was not the lonely hero he was considered to be in the nineteenth century. From the viewpoint of historical epistemology, Galileo was working on the basis of structured bodies of physical knowledge which he shared with his contemporaries. This knowledge opened up a field of standard applications to specific objects as well as to the construction of global world models and raised a number of open problems and alternative options for solving them. His work was furthermore constrained by certain images of knowledge, in the sense of controversial interpretations of the social status and the cultural meaning of these knowledge systems. Within this epistemic cosmos, defining the space for the trajectories of individual scientists, both common aims and tools of Galileo and his contemporaries, as well as the space of alternative interpretations, were determined.

A reconstruction of the emergence and dissemination of a new theory of motion in early modern Europe cannot really be successful as long as it is merely understood as the consequence of the reception of the isolated discoveries of Galileo. If those who built on his achievements were standing on the shoulders of a giant, this giant was represented not so much by these

[52] Bonaventura Cavalieri to Galileo, September 21, 1632, Galilei, G., 1890-1909, XIV: 395; see also the discussion of this correspondence in Wohlwill, E., 1899.

discoveries but rather by the shared heritage of early modern Europe that made the pioneering achievements of Galileo and his contemporaries meaningful in the first place. Such an understanding of scientific progress requires analyzing not only sources in order to identify exceptional events which can then be designated as "discoveries". It rather makes it necessary to reconstruct the bodies and images of knowledge representing what one might call "normal planning, reflecting, and teaching activities". From this perspective, the study of Galileo's unpublished treatises documenting such activities may turn out to be even more revealing than any attempt to identify singular discoveries in his published works.

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