Galileo and the Challenge of the Arsenal

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Summary

The paper examines the empirical foundation of Galileo's two new sciences, presented in the *Discorsi*. It argues that the second of these sciences, Galileo's theory of motion, is largely rooted in the practical knowledge on ballistics as it was accumulated by contemporary experts on artillery. The empirical roots of the first of his two new sciences, dealing with the strength of materials, are analyzed on the basis of new sources documenting the practical challenges of the construction of large galleys as they were faced by the foremen of the Venetian Arsenal.

Riassunto

L'articolo esamina la fondazione empirica delle due nuove scienze galileiane presentate nei *Discorsi*. Si sostiene che la seconda di queste scienze, la teoria del moto, abbia radici nelle conoscenze pratiche correlate alla balìstica e, quindi, accumulate da contemporanei esperti d'artiglieria. Il fondamento empirico della prima delle due nuove scienze di Galileo, che tratta della resistenza dei materiali, è analizzato sulla base di nuove fonti che documentano problematiche emerse tra gli artigiani dell'Arsenale di Venezia e dovute alla costruzione delle cosiddette "galere grosse."

The vexing introduction to the *Discorsi*[1]

Towards the end of his life, persecuted by the Inquisition, isolated and under house arrest in his villa in Arcetri, Galileo laboriously compiled the results of his life-long quest for a new understanding of motion and mechanics. These were eventually published in 1638 in his major scientific work at the dawn of classical mechanics, the *Discorsi e dimostrazioni matematiche intorno a due nuove scienze*. The *Discorsi* are written as a dialogue. Its speakers, who often enter upon the various topics with irony, also look back at the tortuous history of Galileo's accomplishments and introduce reflections about the roots of his insights, even about the wrong tracks he pursued before achieving them.

Recent studies of his unpublished manuscripts have revealed the strikingly accurate autobiographical character of these reflections, occasionally challenging the received view of his discovery process.[2] Accordingly, we may well believe in Galileo's words, even when Simplicio speaks, although he is usually considered to be merely the Aristotelian opponent of Galileo's ideas. As a matter of fact, however, he often represents the spokesman of the young Galileo, expressing ideas that Galileo had meanwhile overcome but that were still shared by his contemporaries. It is worth therefore reconsidering Galileo's famous and often quoted introduction to the summa of his research in mechanics which, however, has so far been neglected as a clue to its origins. For this reason we have decided to focus this *Lettura Galileiana* on the well-known words with which Salviati, Galileo's direct spokesman in the dialogue, opens the First Day:[3]

> Frequent experience of your famous arsenal, my Venetian friends, seems to me to open a large field to speculative minds for philosophizing, and particularly in that area which is called mechanics, inasmuch as every sort of instrument and machine is continually put in operation there. And among its great number of artisans there must be some who, through observations handed down by their

1. GALILEI GALILEO, *Discorsi e dimostrazioni matematiche: intorno à due nuoue scienze attinenti alla mecanica e ai movimenti locali*, Leida, Appresso gli Elsevirii, 1638. See also GALILEO GALILEI, ANTONIO FAVARO (ed.), *Le Opere di Galileo Galilei*, Firenze, Barbera, 1968, Vol. VIII, and GALILEO GALILEI, ENRICO GIUSTI (ed.), *Discorsi e dimostrazioni matematiche intorno a due nuove scienze attinenti alla mecanica ed i movimenti locali*, Torino, Einaudi, 1990.
2. See, in particular, JÜRGEN RENN, PETER DAMEROW, SIMONE RIEGER, «Hunting the White Elephant: When and How did Galileo Discover the Law of Fall?», *Science in Context*, 13, fasc. 3/4, 2000, pp. 299-419.
3. GALILEI, FAVARO (ed.), *Le Opere di Galileo Galilei*, cit., Vol. VIII, p. 49. English translation from GALILEO GALILEI, STILLMAN DRAKE (ed.), *Two New Sciences: including Centers of Gravity and Force of Percussion*, Madison, University of Wisconsin Press, 1974, p. 11.

> predecessors as well as those which they attentively and continually make for themselves, are truly expert and whose reasoning is of the finest.

The prominence we have chosen to give to this text raises several questions. First of all, why, in a *Lettura Galileiana* held in Florence and dedicated to a great Tuscan scientist, focus on Venice? And why did Galileo himself give so much prominence not just to Venice in general but specifically to its Arsenal? Why did he introduce the two new sciences whose theoretical foundation is the central concern of his work with a passage praising the practical knowledge of the expert artisans working in the Arsenal? The answers are related to the sources that we will discuss in the following.[4]

But before attempting to provide answers, we would like to briefly recall the essence of the two new sciences expounded by Galileo in the *Discorsi*. Galileo's first new science, discussed in the first two Days, deals with the strength of materials. It is built around the model of a cantilever beam projecting from a solid wall and loaded with an additional weight at its free end. Galileo analyzes the dependence of the beam's resistance to breaking on its geometrical shape and its own weight by applying the law of the lever to this model. He interprets the thickness of the beam as one lever arm, and its length as the other. He concludes that geometrically similar beams are not equally strong but become weaker with increasing dimensions and may eventually break under the action of their own weight.

Galileo's second new science, presented in the Third and Fourth Day of the *Discorsi*, deals with accelerated motion. Its central model is a falling body – either freely or along an inclined plane – moving in such a way that its distance from the starting point increases with the square of the time elapsed. If this motion of fall is superposed with a uniform motion along the horizontal, a projectile trajectory of parabolic shape results.

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4. These sources discussed below are notes taken by Giacomo Contarini in the Venetian Senate in 1593; they are preserved in the Venetian State Archive (Archivio Proprio Contarini, b. 25). It is planned to make them accessible on the Internet in the context of a joint project by the Venetian State Archive and the Max Planck Institute for the History of Science. We would like to thank Mary Henninger Voss for drawing our attention to them. For a discussion of the potential of digital representations of sources for the history of science as well as of the limits imposed on this potential by restrictive political laws (such as the Italian laws n. 633, 1941; n. 248, 2000; n. 4, 1993) and the commercialization of culture, see PETER DAMEROW, JÜRGEN RENN, «Galileo at Work: his Complete Notes on Motion in an Electronic Representation», *Nuncius*, XIII, 2, 1998, pp. 781-790 and A. PATRON (ed.), *Il nuovo diritto d'autore. Manuale teorico e pratico. Disciplina nazionale ed internazionale della tutela della proprietà intellettuale dopo la legge 248, 2000*, Edizioni Simone, 2001.

Galileo’s establishment of the law of fall and of the parabolic shape of the trajectory became essential building blocks of classical mechanics.

No doubt, both of Galileo’s two new sciences had a long-range impact not only on theoretical mechanics but also on the development of various fields of technology, ranging from architecture to artillery. It is, however, less obvious and has been hardly discussed among historians to which extent Galileo’s achievements are also *rooted* in practical knowledge such as that of the artisans mentioned in the introduction to the *Discorsi*. Most historians have in fact not even seriously considered the possibility that Galileo’s reverence for the Venetian Arsenal provides a hint at the roots of his science in practical knowledge. Alexandre Koyré, for instance, wrote:[5]

> And Galileo did not learn his business from people who tolied in the arsenals and shipyards of Venice. Quite the contrary: he taught them *theirs*.

That practical knowledge was not a central component of Galileo’s science was also the opinion of Stillman Drake, although he disagreed with Koyré on almost everything else. What mattered according to Drake were neither philosophers nor practitioners but those:[6]

> who [...] sought to find sure particular limited rules by careful measurements.

Even those historians who, like Edgar Zilsel, did emphasize the role of craftsmanship as a framing condition of early modern science, failed to take it seriously as a concrete source for its empirical knowledge. Zilsel assumed, in particular, that the essential contribution of craftsmanship to the emergence of science was of a methodological character:[7]

> Real science is born when, with the progress of technology, the experimental method of the craftsmen overcomes the prejudice against manual work and is adopted by rationally trained university-scholars. This is accomplished with Galileo (1564-1642).

In contrast Salvatore Di Pasquale, in his pioneering book *L’arte del costruire*, clearly states his conviction that:[8]

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5. ALEXANDER KOYRÉ, «Galileo and Plato», *Journal of the History of Ideas*, IV, 4/ 1943, p. 401.
6. STILLMAN DRAKE, «Galileo's Notes on Motion Arranged in Probable Order of Composition and Presented in Reduced Facsimile», *Supplemento agli Annali dell'Istituto e Museo di Storia della Scienza*, fasc. 2 (Monografia 3), 1979, p. VII.
7. EDGAR ZILSEL, DIEDERICK RAVEN, et al. (eds.), *The Social Origins of Modern Science*, Dordrecht, Kluwer, 2000, p. 5.
8. SALVATORE DI PASQUALE, *L'arte del costruire. Tra conoscenza e scienza*, Venezia, Marsilio, 1996, p. 53.

> The problem of the resistance of materials emerges from daily experiences which do not find their place within the theory of architecture[...].

His interpretation is supported by an impressive reconstruction of the break, represented by Galileo’s theory, with the traditional theory of architecture. Concerning the roots of Galileo’s theory in practical knowledge, however, also Di Pasquale limits himself to stressing the appropriateness of referring to the Venetian Arsenal in the opening scene of the *Discorsi*, without taking into account the actual experiences gathered by its artisans and engineers.

In summary, across a broad spectrum of interpretations, Galileo’s evocation of the Arsenal is generally considered as a literary *topos*, which provides an appealing setting for the ensuing dialogues, but not as a revelatory clue to the origins of his science. And yet, this explanation remains unsatisfactory in the light of Galileo’s intriguingly concise reference to encounters with the workmen of the Venetian Arsenal.

In fact, Galileo, with the voice of one of the dialogue partners, not only refers to his habit of visiting the Arsenal and watching the activity of those artisans that, in Galileo’s words, “for a certain predominance they have on the rest of the masters, we call *Proti*.” He also claims that talking with them has helped him in the investigation of “effects not only magnificent, but also recondite and unimaginable.” He even mentions a specific remark by a “venerable workman” that at first provoked skepticism but then was found acceptable. It is precisely this remark which actually becomes the core idea of the first new science expounded by Galileo; in the words of Galileo’s spokesman Salviati:[9]

> You mean, perhaps, that last remark that he offered when we were trying to comprehend the reason why they make the sustaining apparatus, supports, blocks, and other strengthening devices so much larger around that huge galley that is about to be launched than around smaller vessels. He replied that this is done in order to avoid the peril of its splitting under the weight of its own vast bulk, a trouble to which smaller boats are not subject.

The fact that Galileo attributes the core idea of his first new science to a workman of the Arsenal was apparently so outrageous to Arthur von Oettingen, author of the German translation of the *Discorsi*, that he decided to simply change Galileo’s text in this passage. In his rendering, the author of the crucial idea is no longer the workman but Galileo himself represented by Salviati:[10]

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9. GALILEI, FAVARO (ed.), *Le opere di Galileo Galilei*, cit., Vol. VIII, p. 49. English translation from GALILEI, DRAKE (ed.), *Two New Sciences*, cit. p. 11.
10. GALILEO GALILEI, *Unterredungen und mathematische Demonstrationen über zwei neue Wissenszweige, die Mechanik und die Fallgesetze betreffend: erster bis sechster Tag*, transl. of A. v. Oettingen, Frankfurt am Main, Deutsch, 1995, (4th ed.), pp. 3-4, first published in 1890-1904. Our translation into English.

> You mean, perhaps, that last theorem on which <u>I recently lectured you</u>, [...] <u>You remarked</u> that this is done in order to avoid the peril of its splitting under the weight of its own vast bulk [...].

The effective disappearance of the *Proti* of the Venetian Arsenal from the prevailing reading of Galileo's last major work may already in itself constitute a sufficient reason to dedicate this *Lettura Galileiana* to the vexing introduction of the *Discorsi*.

Galileo as an engineer-scientist

How does one have to interpret the fact that Galileo drew, according to his own testimony, on the knowledge and experience of the workmen of the Arsenal? Is it conceivable that a book like the *Discorsi* could just as well have been written also by a *Proto*? Or does Galileo's new science owe its existence to the lucky coincidence of a theoretician, being at the right place to receive an input from experience?

In our view such questions cannot be satisfactorily answered in terms of the traditional, essentially ahistorical understanding of the relation between theory and experience according to which there is a clear and unassailable distribution of work between the two, one providing the empirical raw material and the other the explanations for it. In the following we will therefore reconsider the relation between Galileo's theories and the practical knowledge represented by the Arsenal from the perspective of a historical epistemology, focussing on the historical development of systems of knowledge including their differentiation into practical and theoretical dimensions.

That a categorical distinction between theoreticians and practitioners is not adequate to the historical context of Galileo's science becomes evident when considering Galileo's own activities without the bias of focussing on what, from a later perspective, was their most significant outcome. On the one hand, there can be no doubt that Galileo was well familiar with the theoretical traditions of his time, including the natural philosophy of scholasticism. His early mastery of Euclidean geometry and Archimedean statics had impressed scientists such as Guidobaldo del Monte who subsequently became Galileo's patron, helping him to acquire his positions first in Pisa and later in Padua. But at the time when Galileo visited the Arsenal, his interests had substantially changed and undergone what we have called a "practical turn."[111] Indeed, when he settled in the Venetian Republic in 1592 he began to design, produce, and sell mathematical instruments, give private lessons, and develop new machinery. His household in this period must have more resembled an officers training camp than the studio of a lonely

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11. [1] For an extensive discussion of this issue, see RENN, DAMEROW, RIEGER, «Hunting the White Elephant», cit.

theoretical thinker who only on Sundays granted himself an outing that might even have included a visit to the Arsenal. As the notes documenting the administration of his household amply testify, Galileo was himself rather an engineer-scientist of a similar type to those that could also be found in the Arsenal.[12]

A fresh look at Galileo's activities in his early Venetian years, including his practical concerns, hence also promises clues for a more general understanding of the interaction between practical and theoretical knowledge and of its role in the emergence of early modern science. In the following, we will consider, in particular, two exemplary documents of this period, each related to one of Galileo's two new sciences.

The discussion of the first document, an outline for a treatise on artillery, aims at showing that Galileo's theory of accelerated motion relied on knowledge accumulated by the practitioners of artillery. The analysis of the second document, a letter from Galileo to a Commissioner of the Arsenal, allows us to reconstruct, in connection with newly found documents revealing the context of this correspondence, how Galileo's theory of the strength of materials emerged from practical challenges of construction technology that became particularly evident at the Arsenal during this period.

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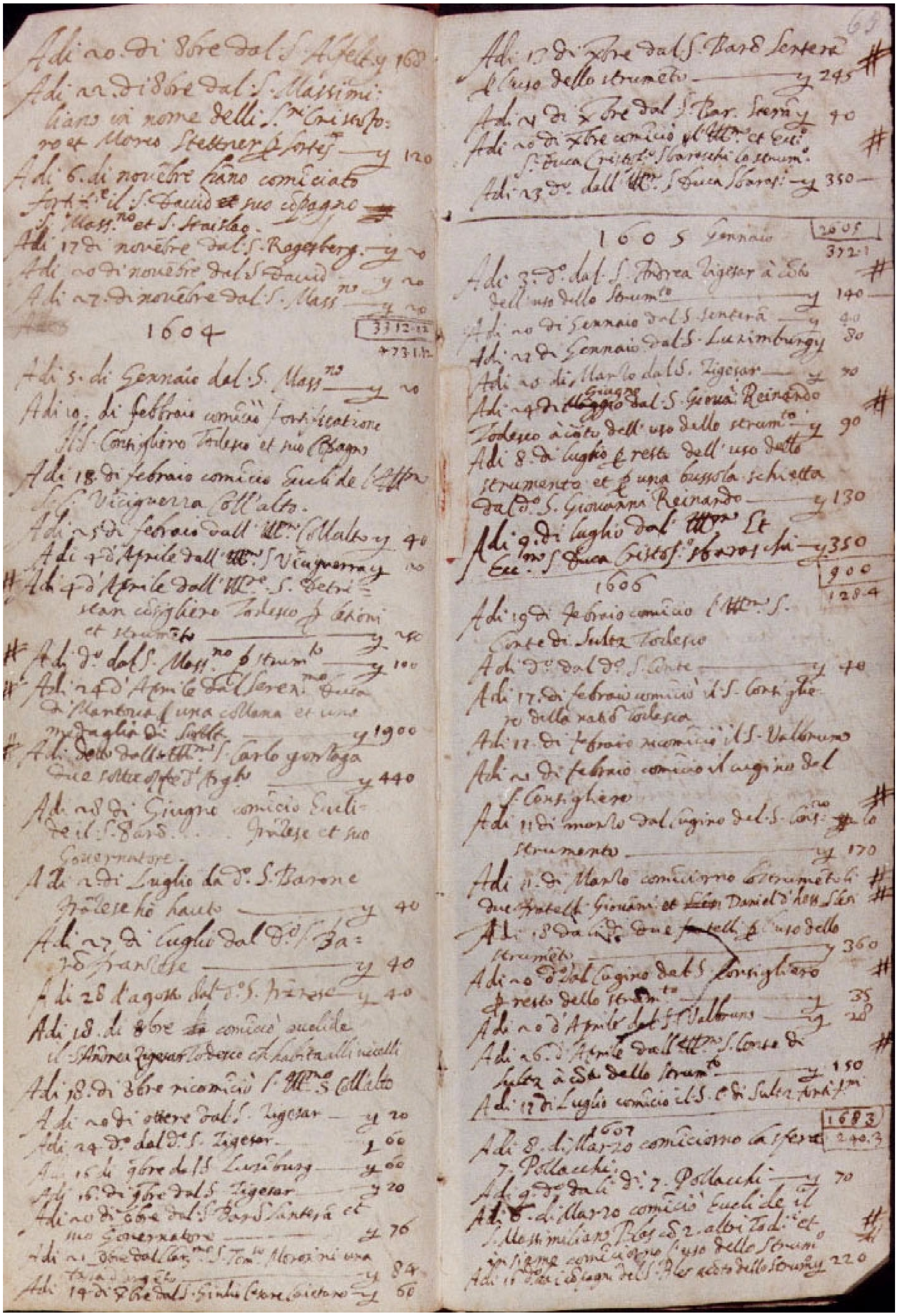
12. For an extensive discussion of these notes, see MATTEO VALLERIANI, «A View on Galileo's Ricordi Autografi. Galileo Practitioner in Padua», JOSÉ MONTESINOS, CARLOS SOLÍS (eds.), Largo campo di filosofare. Eurosymposium Galileo 2001. La Orotava, Fundación Canaria Orotava de Historia de la Ciencia, 2001, pp. 281-291.



Galileo's register of his household. Galilei G., Ms. Gal. 26, 65r, B.N.C.F., Florence, 1598-1634.

Galileo as a teacher of artillery

Among his papers Galileo left the outline of an unwritten treatise entitled "Particular privileges of the artillery with respect to other mechanical instruments",[13] probably dating back to his early years in Padua. The planned treatise was possibly related, just as other writings extant from this period such as the treatise *Le Mecaniche*[14] or the writings on the military compass, to Galileo's private teaching. This essentially followed a curriculum which covered the whole spectrum of issues needed for the education of military officers. The following selection from topics listed in Galileo's outline make it indeed clear that his planned treatise was not intended to expound a new theory of motion but to deal with issues of practical interest to military commanders and artillerists:

> […]
>
> If one operates with a greater force in a certain distance or from nearby
>
> If the ball goes along a straight line if it is not [projected] along the vertical
>
> Which line the ball describes in its [course]
>
> On the course and the time of charging the canon
>
> […]
>
> 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
>
> […]

Although the purpose of the planned treatise was not comparable to that of Galileo's later deductive treatment of projectile motion in the fictive treatise *De Motu locali* presented by Salviati in the *Discorsi*, basic insights on which the latter treatise was founded were evidently already part of Galileo's exposition of ballistics for practitioners. In particular, he refers to the elevation of maximum range shots, the symmetry of the trajectory, its continuous curvature, and clearly indicates that he knows its shape.

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13. GALILEO GALILEI, Mss. Gal, Ms. Gal.. 72, Florence, B. N. C. F., 1602-1637, 193r. For the electronic representation of the manuscript made available by Biblioteca Nazionale Centrale di Firenze, the Istituto e Museo di Storia della Scienza di Firenze, and the Max Planck Institute for the History of Science in Berlin, see http://galileo.imss.firenze.it/ms72 and http://www.mpiwg-berlin.mpg.de/Galileo_Prototype/MAIN.HTM
14. GALILEI, FAVARO (ed.), Le opere di Galileo Galilei, cit. Vol. II, pp. 155-191.

Galileo’s compilation of issues is typical for military treatises of the time. All these treatises, in fact, reflect the *shared knowledge* of the practitioners of ballistics, primarily transmitted by participation and oral transmission. It was, for instance, part of the basic professional experience of artillerists that the speed of a projectile increases with the force the exploding powder exerts on it, that an increased weight of the projectile 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. Any theory of projectile motion advanced at that time had to take into account this common knowledge of the practitioners of ballistics so that it was only a matter of time before all such issues could be more or less satisfactorily embedded within a coherent theory of motion.

It has turned out that also those aspects of Galileo’s adaptation to this shared knowledge by which he distinguished himself from the prevailing view, such as his claim of the symmetry of the trajectory, were nevertheless rooted in the same kind of practical knowledge.[155] Hints at the roots of Galileo’s insights are found in the notebooks of two intellectual companions of his early years in the Venetian Republic, Guidobaldo del Monte and Paolo Sarpi. The significance of their notes for the reconstruction of the origin of Galileo’s new science has long been overlooked because they, just as Galileo’s outline, deal neither with careful measurements nor with quantitative laws. Even the fact that the notes of the two authors provide concurring pieces of information and bear clear indication that they are both based on a common source, namely Galileo, has been disregarded until recently. When taken together, the notes allow the conclusion that, in the summer of 1592, in Montebaroccio near Pesaro, Galileo and Guidobaldo del Monte performed a qualitative experiment on projectile motion. Such experiments were nothing unusual at the time and had been performed also by many other contemporaries interested in artillery such as Aquilone, Puchner, or Bourne.[166] The experiment of Galileo and Guidobaldo consisted in throwing an inked ball across an inclined plane so that it left a trace along its course constituting a record of the ball’s trajectory. In his

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15. [5] For a more extensive account of what follows in this section, see RENN, DAMEROW, RIEGER, «Hunting the White Elephant», cit.
16. [6] For an analysis of contemporary ballistic knowledge, see JOCHEN BÜTTNER, PETER DAMEROW, JÜRGEN RENN, MATTHIAS SCHEMMEL, The Challenging Images of Artillery - Practical Knowledge at the Roots of the Scientific Revolution, to appear in WOLFGANG LEFÈVRE, JÜRGEN RENN, URS SCHOEPFLIN (eds.), The Power of Images in Early Modern Science, Birkhaeuser (in press).

notes about the experiment Guidobaldo stresses the rough character of the experiment but also what he considered to be its striking outcome, the symmetry of the trajectory:[177]

> Although the ball bounces along, yet it makes points as it goes, from which one can clearly see that as it rises so it descends [...].

Paolo Sarpi similarly notes:[188]

> [...] in everything and all the time the descending is similar to the ascending.

In Galileo's handcopy of the *Discorsi*, preserved at the *Biblioteca Nazionale* in Florence,[199] a sheet of paper is inserted showing curves closely resembling Galileo's own description of the outcome of the same experiment which he introduces in the *Discorsi* as a method for drawing parabolas useful to the practitioner. In fact, the two curves on this sheet show the typical characteristics of the traces left by this experiment: the indications of the bouncing of the ball at the beginning and the slight deformation of the parabola at the end due to friction.

Clearly this artifice was not a sophisticated quantitative experiment and therefore was not taken seriously by historians like Drake. Also the outcome of this experiment is not formulated as a proposition that would be acceptable or even recognizable in classical mechanics. The alleged symmetry of the trajectory is rather justified in Aristotelian terms by appealing to its dynamical generation from the violent force of the shot and the natural tendency of a heavy body to fall downwards. As Guidobaldo puts it:[200]

> [...] and it is reasonable this way, since the violence it has acquired in its ascent operates so that in falling it overcomes, in the same way, the natural movement in coming down [...].

Guidobaldo already mentions the possibility of identifying the trajectory with well-known mathematical curves such as a parabola or a hyperbola. On closer inspection,

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17. [7] GUIDOBALDO DEL MONTE, Meditantiunculae Guidi Ubaldi e marchionibus Montis Santae Mariae de rebus mathematicis, Paris, Bibliothèque Nationale de Paris, Manuscript, Catalogue No., Lat. 10246. English translation from RENN, DAMEROW, RIEGER, «Hunting the White Elephant», cit., p. 315. See also PETER DAMEROW, GIDEON FREUDENTHAL, PETER MCLAUGHLIN, JÜRGEN RENN, Exploring the Limits of Preclassical Mechanics, New York, Springer, 1992, p. 337.
18. [8] PAOLO SARPI, COZZI LUISA and LIBERO SOSIO (eds.), *Pensieri naturali, metafisici e matematici*, Milano-Napoli, Riccardo Ricciardi Editore, 1996, p. 398. English translation from RENN, DAMEROW, RIEGER, «Hunting the White Elephant», cit., p. 330.
19. [9] GALILEO GALILEI, *Discorsi (annotated copy of Galileo)*, Florence, BNCF, Mss. Gal., Ms. Gal. 79, after 1638.
20. [0] DEL MONTE, *Meditantiunculae Guidi Ubaldi e marchionibus Montis Santae Mariae de rebus mathematicis*, cit. English translation from RENN, DAMEROW, RIEGER, «Hunting the White Elephant», cit., p. 315.

dynamical reasons exclude the option of a hyperbola, since it would imply a steadily growing violent component of the motion. Hence this simple qualitative experiment, in line with similar ones undertaken by contemporary artillerists, evidently provided sufficient ground for somebody familiar with the mathematical tradition to conjecture that the shape of the projectile trajectory is a parabola, and, by implication, also to assume that the natural downward motion obeys the times-squared law of fall.

However, both Guidobaldo's and Sarpi's notes agree in emphasizing another implication of the experiment, the resemblance of the trajectory to the catenary, the curve of a hanging chain. For Galileo in 1592, this was apparently the key result which suggested also that both curves are generated in an analogous way from the composition of a violent force and the natural tendency downwards. The realization of this dynamical analogy, conceptualized in terms of Aristotelian natural philosophy, confirmed the conclusion of the symmetry of the trajectory which could hardly be inferred from the experiment itself.

Although erroneous from a modern point of view, the supposed equivalence of trajectory and catenary became a corner stone of the development of Galileo's theory of motion. However he embarked on the construction of such a theory only much later and, for the time being, used his insightsonly in order to improve the teaching of military architecture as is illustrated by the outline quoted above. After the practical turn of 1592, the beginning of his systematic theoretical effort marks in fact another turning point in Galileo's scientific biography which can be associated with a letter he wrote in 1604 to Paolo Sarpi. The letter begins by raising the problem of the axiomatic foundation of a new theory of motion:[21]

> Thinking again about the matters of motion, in which, to demonstrate the phenomena observed by me, I lacked a completely indubitable principle which I could pose as an axiom, I am reduced to a proposition which has much of the natural and the evident: and with this assumed, I then demonstrate the rest [...].

The effort to develop a deductive theory of motion which is documented by this letter builds on a foundation that already includes a familiarity with the law of fall and essential properties of projectile motion. The question of the origin of this knowledge has long struck Galileo scholars as a virtually unresolvable puzzle. According to our reconstruction, this empirical foundation of the new science of motion was provided by the practical knowledge which engineer-scientists such as Galileo could acquire when

21. Galileo Galilei to Paolo Sarpi in Venice, October 16, 1604 in GALILEI, FAVARO (ed.), *Le opere di Galileo Galilei*, cit., Vol. X, n. 105, p. 115. English translation from RENN, DAMEROW, RIEGER, «Hunting the White Elephant», cit., p. 407.

confronting the challenging objects of contemporary craftsmanship and engineering, such as artillery, the chain, or the pendulum, and by the reflection of this practical knowledge in the light of theoretical traditions such as Euclidean geometry and Aristotelian natural philosophy.

The roots of Galileo's insights into the laws of projectile motion in the practical knowledge of artillery and in his early qualitative experiment remain visible even in the presentation of his mature theory of motion. The *Discorsi* not only contain a description of the experiment and the identification of chainline and trajectory but also announce a method of how to turn the chain into an instrument for gunners, allowing them to determine the trajectory for a given elevation of the shot.[22] This promise remains, however, unfulfilled in the *Discorsi* which were published before Galileo could complete them as planned. But fortunately, a manuscript sheet has been preserved which documents how he intended his method to work.[23] The sheet also contains the sketch for a proof of his erroneous claim that the catenary is, just as the trajectory, a parabola, thus concluding a project he had begun more than 40 years before, albeit from a different perspective.

Galileo as an apprentice of naval architecture

The biography of Galileo embraces contrasting experiences such as teaching artillery and serving the Grand Duke of Tuscany as Court Philosopher so that, during his life, practical and theoretical knowledge have often crossed paths. An exclusively biographical approach does not explain, however, the social and institutional conditions which enabled the integration of these different levels of knowledge. For this reason, turning to the other of the two new sciences, that of the strength of materials, we will adopt a perspective in which not Galileo but the Arsenal plays the central role precisely because it provided the institutional setting for such an integration of knowledge.

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22. For Galileo's treatment of this issue in the *Discorsi*, see GALILEI, FAVARO (ed.), *Le opere di Galileo Galilei*, cit., Vol. VIII, Corollarium p. 296, Propositio XII and XIII, pp. 304-313.

23. GALILEO GALILEI, Mss. Gal, Ms. Gal.. 72, Florence, B. N. C. F., 1602-1637, 43r. For the electronic representation of the manuscript made available by Biblioteca Nazionale Centrale di Firenze, Istituto e Museo di Storia della Scienza di Firenze, and the Max Planck Institute for the History of Science in Berlin, see http://galileo.imss.firenze.it/ms72 and http://www.mpiwg-berlin.mpg.de/Galileo_Prototype/MAIN.HTM

The Arsenal was one of the largest and technologically most advanced industrial centers of the time, covering sixty acres of ground and water, employing between one and two thousand workers, and annually spending between one and two hundred thousand ducats.[24] In 1590, two years before Galileo settled in the Venetian Republic, 200 ship carpenters, 450 caulkers, and 100 oarmakers were employed by the Arsenal. Eighteen large galleys and 118 light galleys were finished or being built in this year.[25] The Arsenal was subject to an elaborate industrial management comprising complex structures of supervision and accounting. The Lords and Commissioners of the Arsenal formed its board of management, responsible for the munitions, maintenance, and construction departments.[26] Together with the Admiral, responsible for storage, assemblage, and refitting, and the Proti of the carpenters, caulkers, mast-makers, and oarmakers, the Lords of the Arsenal constituted a committee responsible for planning the work at the Arsenal.[27] The governing bodies also had to translate political and military needs into requirements for the output of the Arsenal, often amounting to extreme technical challenges as when, in the summer of 1574, Henry III, King of France, visited Venice and a galley had to be built, launched, and completely armed, for his royal entertainment, all in one hour, apparently.[28]

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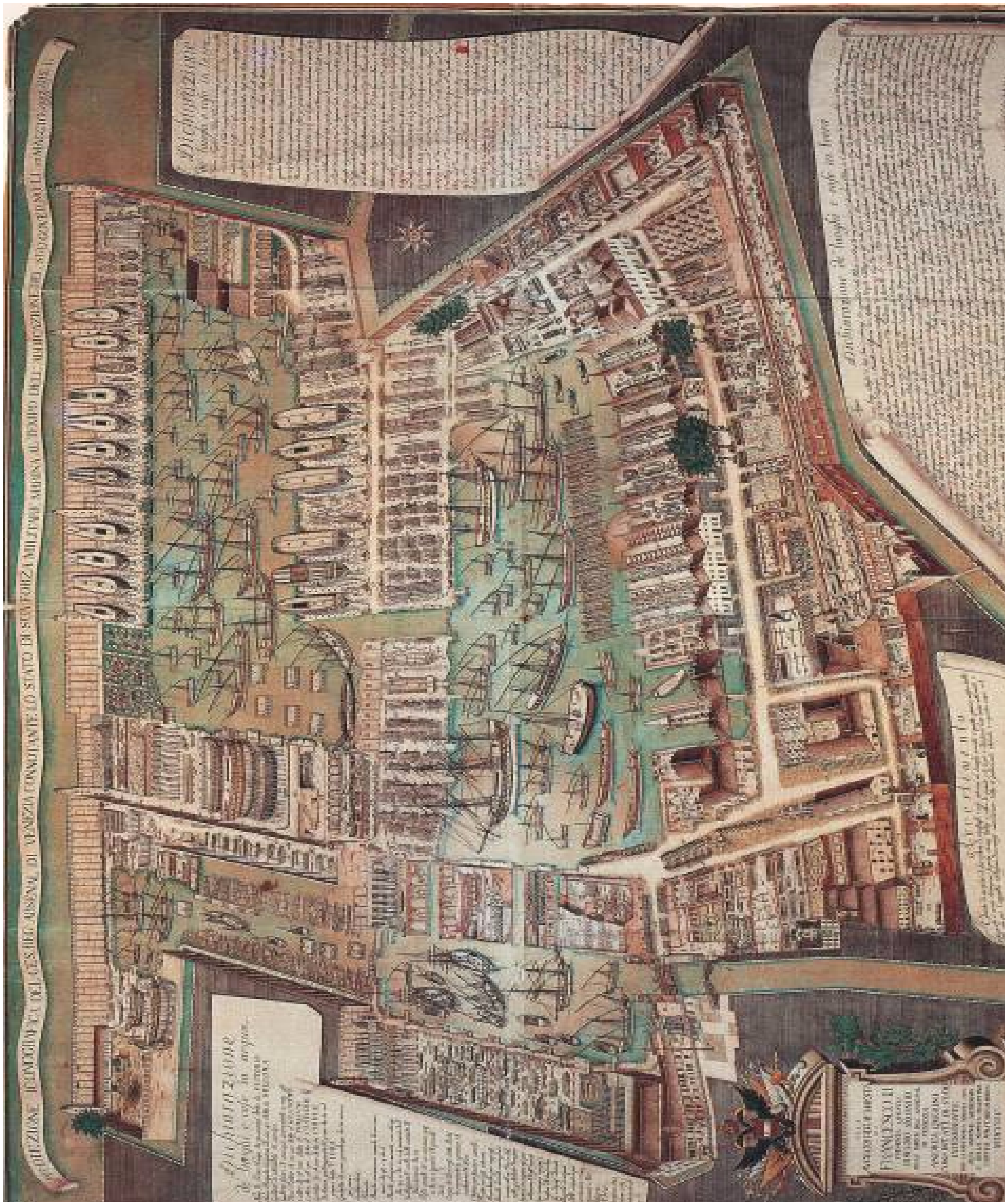
24. The following information is taken from FREDERIC CHAPIN LANE, *Venetian Ships and Shipbuilders of the Renaissance*, New York, Arno Press, 1979, p. 146.
25. LANE, Venetian Ships, cit., p. 242-243.
26. LANE, Venetian Ships, cit., p. 148.
27. LANE, Venetian Ships, cit., p. 164.
28. LANE, Venetian Ships, cit., p. 144.



Iconographic projection of the Arsenal in Venice. Maffioletti G., Disegno II, Archivio Diplomatico della Biblioteca Civica di Trieste, Trieste, 1797.

In view of such a grand display of technological power, it is difficult to imagine that the association between this large industrial center and a professor at the University of Padua, who increased his income by entertaining a workshop and giving private lessons, could have been anything but a casual event. Was thus Galileo's reverence to the Arsenal in the introduction to the *Discorsi* nothing but a faint echo of the impression this gigantic enterprise must have made on him?

Fortunately, we not only have later reminiscences at our disposal but also a contemporary document, a letter by Galileo dated March 22, 1593, to one of the Commissioners of the Arsenal, Giacomo Contarini. Although this brings us back, for the time being, to a biographical perspective, we would like to take a closer look at this document which so far has played virtually no role in the reconstruction of Galileo's science. Galileo's letter is a reaction to an enquiry by Contarini which reached Galileo by the mediation of Gianvincenzo Pinelli, in whose circle Galileo had met many of his Venetian acquaintances such as Paolo Sarpi.[29] Contarini had evidently confronted Galileo with a practical problem and asked him for his advice. From Galileo's answer one can conclude that this problem must have concerned the propulsion and manoeuverability of a galley and the optimal position of its oars for that purpose. Galileo addressed, in particular, the question of whether it was more advantageous to place the support of the oars within the interior of the ship or on external superstructures. He opens his letter with the flat claim that this makes no difference:[30]

> In reference to exerting more or less force in pushing forward the vessel, the oar being supported within the interior or on the outside, it does not make any difference, being all other circumstances the same [...].

After having justified this claim, Galileo expressed his opinion on how a more powerful propulsion could actually be achieved:

> […], if the same part between the support and the force will be shorter, then the water will be able to be moved by the blade with greater difficulty, and consequently, since I need it as a support, it will be more solid, and one will be able to push the vessel with more force.

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29. For the context of the relations between Pinelli and Galileo, see G. Vincenzo Pinelli to Galileo Galilei in Venice, September 3, 1592, and G. Vincenzo Pinelli to Galileo Galilei in Venice, September 9, 1592 in GALILEI, FAVARO (ed.), *Le Opere di Galileo Galilei*, cit., Vol. X, n. 36, p. 47, and n. 37, p. 48. See also ANTONIO FAVARO, *La venuta di Galileo a Padova*, in ANTONIO FAVARO, *Galileo Galilei e lo studio di Padova*, I, Padova, Editrice Antenore, 1966, pp. 36-40.
30. Galileo Galilei to Giacomo Contarini in Venice, March 22, 1593, in GALILEI, FAVARO (ed.), Le opere di Galileo Galilei, cit., Vol. X, n. 47, p. 55.

From a practical point of view Galileo's proposal is surprising. It amounts to the assertion that an optimal propulsion is reached if, so to say, life is made as difficult as possible for the oarsmen by reducing the length of that part of the oar which is inside the ship. How did Galileo arrive at this astonishing and rather impractical conclusion?

Galileo followed an ancient tradition of mechanical thinking founded on the "Mechanical Questions" traditionally ascribed to Aristotle. As has been shown in the context of a research project on the epistemic history of mechanics, the explanation of mechanical devices, given in this text, are based on a knowledge representation structure emerging from practical experience that can best be described as a *mental model* in the sense of cognitive science.[31] A mental model allows for drawing inferences about complex objects and processes even when only incomplete information is available on them. It consists of a relatively stable structure relating variable inputs that are assimilated to the "slots" of the model. The mental models shared by a specific group of practitioners are closely linked to the tools and techniques they employ and are transmitted by practice and professional training. We have called the specific mental model underlying the "Mechanical Questions" the "balance-lever model."[32] This model allows the explanation of how different mechanical devices can achieve a large effect by applying a small force and is based on experiences not only with the lever but also with unequal-arm balances which had been invented not long before the composition of this text, that documents the origins of mechanics in Greek Antiquity. The force-saving effect of mechanical devices such as a nutcracker is accounted for by matching its elements with the slots of the model, among them those for the moving force, the fulcrum, and the load.

One of the devices treated by Aristotle is the oar. His point of departure is the question:[33]

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31. This research project dedicated, to mental models in the history of mechanics, is presently being pursued at the Max Planck Institute for the History of Science. For an, see JÜRGEN RENN, *Mentale Modelle in der Geschichte des Wissens: Auf dem Wege zu einer Paläontologie des Mechanischen Denkens*, «Dahlemer Archivgespräche», 6, 2000, pp. 83-100.

32. For the balance-lever model, see PETER DAMEROW, JÜRGEN RENN, SIMONE RIEGER, PAUL WEINIG, *Mechanical Knowledge and Pompeian Balances*, in ANNAMARIA CIARALLO et al. (eds.), *Homo Faber: Studies on Nature, Technology, and Science at the time of Pompeii*, L'Erma di Bretschneider, in press.

33. ARISTOTLE, *Mechanical Problems*, transl. By W. S. Hett, London, Harvard University Press, 1980, Problem 4, p. 355.

> Why do the rowers in the middle of the ship contribute most to its movement?

This question was directly relevant to Contarini's problem and had probably also shaped the way he had thought about it, given the widespread diffusion and enormous influence of Aristotle's "Mechanical Questions" in the 16th century which was first made available in Latin by the Venetian humanist Vettor Fausto, famous in Venice for his reconstruction of a *quinquireme* as it was supposedly used in Antiquity.[34] Aristotle's answer is based on assimilating the oar to the balance-lever model:

> Is it because the oar acts like a lever? For the thole-pin is the fulcrum (for it is fixed), and the sea is the weight, which the oar presses; the sailor is the force which moves the lever.

Aristotle then argues that the center of the ship is where the internal part of the oar is largest. From the principle that the further away the moving force is farther away from the fulcrum, the more it moves the weight, he finally concludes that the rowers in the middle of the ship indeed contribute most to its movement.

Following the tradition of Aristotelian mechanics, also Galileo applied, in his answer to Contarini, the balance-lever model to the oar, albeit with a different filling of the slots. He realized that the interpretation of the oar as a lever was rendered difficult by the fact that the ship was in motion:

> The oar is not a simple lever like the others, rather there is a great difference in this [respect]: that the lever ordinarily has a force and a resistance which are movable, and a support which is at rest; but in the galley, the support moves as well as the resistance and the force [...].

From this observation Galileo did not, however, conclude that the oar could not be assimilated to the balance-lever model but rather that this had to be done in a special way which he considered to be a significant innovation. As a matter of fact, he considered two possible ways of applying the balance-lever model:

> [...] support and resistance are the same because, insofar as the blade of the oar sticks in the water, the water comes to be the support, and the bulwark the resistance; but insofar as the water itself is moved by the oar, it is the resistance in this case, and the bulwark is the support.

Evidently, if legitimate, the first mode of application was to be considered more advantageous for the propulsion of the galley:

> And since, when the support is immovable, the whole force is applied to move the resistance, if one arranges the oar so that the water becomes practically immovable, then one will employ practically the entire force to move the vessel; [...]

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34. For a reconstruction of the attempt to rebuild a *quinquireme*, see ENNIO CONCINA, *L'Arsenale della Repubblica di Venezia. Tecniche e istituzioni dal medioevo all'età moderna*, Milano, Electa, 1988, p. 108. For Fausto's translation, see VETTORE FAUSTO, *Aristotelis mechanica / V. Fausti industria in pristini habitum restituta ac latinitate donata*, Paris, Jodocus Badius, 1517.

Galileo’s ideal case thus effectively corresponds to a ship moving on solid ground, using its oars like stilts. In order to approach this ideal case, he argued, it was advisable to make, in contrast to Aristotle’s suggestion, the interior part of the oar as short as possible:

> [...] when the said part between the bulwark and the force will be shorter, then the water can only be moved with greater difficulty by the blade, and consequently, since [the water] serves me as support, it will be more solid, and one will be able to push the vessel with more force.

Contarini’s answer, written less than a week later, makes it immediately clear that the claim by Koyré, according to which Galileo could teach the artisans at the Arsenal their business, can hardly be correct.[35] In fact, Contarini politely instructs Galileo that the division of the oar into an internal and an external part is largely determined by factors which Galileo had entirely disregarded such as the available space for the oarsmen and the motion of the oar within the ship, but also the weight of the external part of the oar which has to be balanced on the inside, and last but not least the limited human force of the oarsmen.

While Contarini courteously concludes his letter with an apology for "having tried to instruct *Minerva* herself,” it is clear that he had actually confronted Galileo with technological challenges going far beyond the capacity of contemporary theoretical means. At first sight, Galileo’s exchange with Contarini thus seems to confirm that his praise of the Arsenal in the *Discorsi* was merely the recollection of an impressive but passing and ultimately inconsequential encounter with a representative of the Venetian Arsenal. It seems, in any case, hardly imaginable that Contarini could have played the role of a midwife for Galileo’s science of materials comparable to that played by Guidobaldo for Galileo’s science of motion.

As a matter of fact, however, Galileo’s relation with Contarini and with the Arsenal was by no means terminated with this correspondence.[36] And, as a closer examination of Contarini’s papers preserved at the Venetian State Archives has now revealed, the exchange between Galileo and Contarini was not at all a casual event, at least if considered from the perspective of the Arsenal. In fact, in Contarini’s files, Galileo’s letter is held together with other documents pertaining to the same problem, considered an issue of high military relevance. An examination of these documents makes it possible to take a closer look at what Galileo could learn from Contarini and his

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35. Giacomo Contarini to Galileo Galilei in Padua, March 28, 1593, in GALILEI, FAVARO (ed.), *Le opere di Galileo Galilei*, cit., Vol. X, n. 48, p. 57.

collaborators in the Arsenal and allows us to draw rather specific conclusions concerning the origin of Galileo's new science of materials.

First of all, the Contarini archives show that the epistolary exchange of 1593 was part of a systematic enquiry undertaken at the request of the military committee of the Republic. As follows from a memorandum by Contarini, dated 9 February 1592[37], that is, less than two months before his exchange with Galileo, such an enquiry was pursued with the aim to find answers to a number of pressing questions reflecting the military and technical developments since the battle of Lepanto in 1571. The increased significance of artillery for naval battles had made it necessary to use larger galleys which posed, however, problems of speed and manoeuverability. One response was to lengthen the oars of such galleys so that they could be handled by several men on the same bench.[38] But the issue was far from being definitively settled in 1593. For this reason *Proti*, craftsmen, veterans, and, due to the mediation of Pinelli, even outside experts such as Galileo were asked a number of specific questions. It was enquired, in particular:[39]

> which approach one has to take to remedy the flaw which the large galleys have in travelling so that, on occasion, they can travel without being towed;
>
> if one has to enlarge the superstructures of these galleys;
>
> which quality of oars and [oars] of which length it will be necessary to apply;
>
> if one has to adjust these galleys to having two oars per bench or one;
>
> the costs which one could encounter in such an adjustment;
>
> the way to then recover these galleys from the Arsenal in case one should enlarge the superstructures (GO TO FOLIO)

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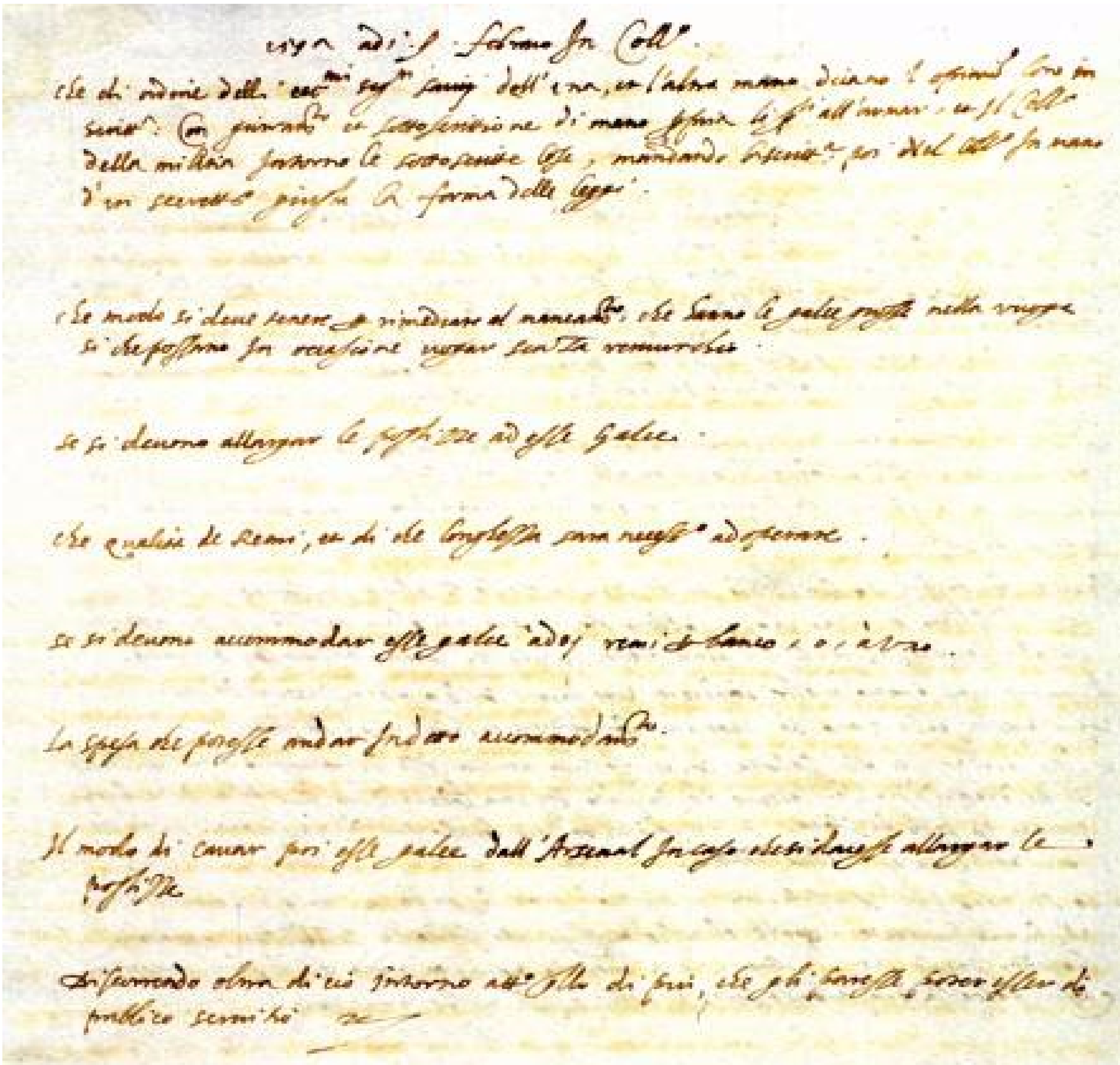
36. Many hints allow us to establish that Galileo remained in confidence not only with Giacomo Contarini but with many members of this Venetian family, whose origins were probably German. For instance, Zaccaria Contarini was one of the *Riformatori dello Studio di Padova* during Galileo's time there and, together with Pietro Contarini, was present at Galileo's exhibition of the telescope from S. Marco's tower. Moreover, we find three young members of Contarini's family as Galileo's students. One of them, Simone, was a Venetian Ambassador in many European courts. Contarini Niccolò lent money to Galileo for the construction of the model of the water lifting machine on September 12 and 29, 1601. For this last information, see GALILEO GALILEI, Mss. Gal., Ms. Gal. 26, Florence, B. N. C. F., 1598-1634, 82v.

37. Due to the local calendar in the Venetian Republic, documents written within the first two months of a year are dated back to the precedent year: for instance, February 9, 1592 corresponds to February 9, 1593.

38. Larger galleys acquired an increasing importance as warships during the second half of the XVI century. For the Venetian sea-battle strategy larger galleys were supposed to form a line in front of the enemies where the larger ships were positioned transversally. Their heavy artillery was able in this way to concentrate their power against the whole first line of the enemies and, therefore, to disorganize them. However, this strategy worked only for the battle of Lepanto in 1571. As a matter of fact, the manoeuvres needed to form the front line could be accomplished only by means of a laborious and long operation that, moreover, was definitively impossible in the case of absence of wind. In fact, larger war galleys were so heavy that, in addition to their own propellent power, they needed to be dragged by one or more light galleys. For the discussion about this issue held in the *Collegio della Milizia da Mar* in Venice in 1593, see GIACOMO CONTARINI, *Fabrica di galee*, in Archivio Proprio Contarini, Busta 25, Archivio di Stato di Venezia, Venezia, 1593. For a general introduction, see also LANE, *Venetian Ships*, cit., pp. 31-34.

39. CONTARINI, *Fabrica di galee*, cit., 1v.



1593 adì 5 febraro in Coll°.

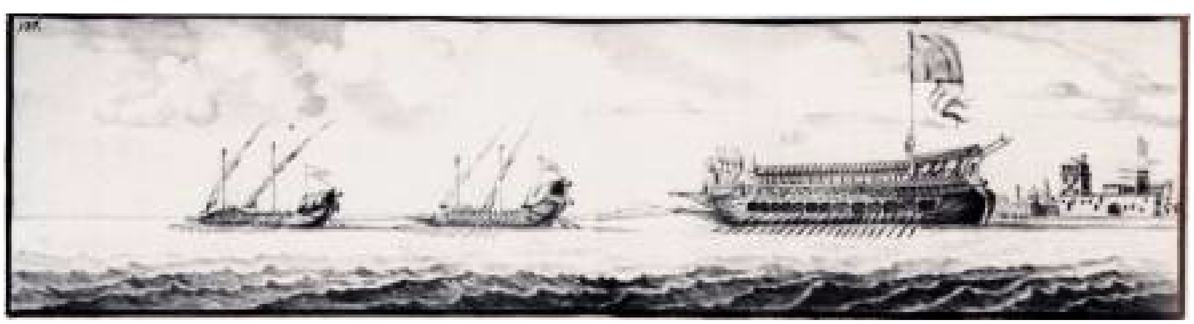
Se si devono allargar le postizze ad esse Galee.

Che qualità de Remi, et di che longhezza sarà necess.° adoperare.

Se si devono accommodar esse galee a doi remi per banco, o a tre.

La spesa che potesse andar in detto accommodam.to

Il modo di cavar fuori esse galee dall'Arsenal in caso che si havesse allargar le postizze



List of questions which open Contarini's protocol and the famous ship *Bucintoro* towed by two light galleys. Contarini G., *Fabrica di galee*, in Archivio Proprio Contarini, Busta 25, Archivio di Stato di Venezia, Venezia, 1593; *Il Bucintoro* from *A voyage into the Mediterranean seas*, Kings. Mss. 40, British Library.

Galileo’s letter is kept together with Contarini's protocols of the answers to these questions by other experts. Among his papers he even included the report on an English royal galley obtained by the Venetian embassy, apparently because he considered it as a potentially relevant source of knowledge on shipbuilding. But what does all of this have to do with the origin of Galileo’s science?

It turns out that the practical knowledge documented by these protocols represents a mine of information concerning the problems resulting from the challenge to enlarge the scale of galleys, precisely the type of problems by which Galileo opens the discussion of the First Day. These problems range from logistical issues, such as the supply of timber or the moving of a large galley through the entrance of the Arsenal, to constructive issues such as the position of the oars discussed by Galileo and Contarini.

The statements of the administrators, technicians, and craftsmen from the Arsenal touched, in particular, on an issue that was to become the central subject of Galileo’s new science, the dependence of the stability of a beam on its dimensions. This issue was central also to the project of building large and yet manoeuverable galleys and presented itself when it came to the dimensions of the oars of these galleys.

Let us hear the voices of the experts. In his testimony, Nicolò Balbi, one of the governors of the military committee, pointed to the problem of the fragility of enlarged oars:[40]

> […] and extending to the outside the superstructures one single foot, one would have to consequently enlarge the beam of the oar to the point that the one of 36 feet would become 40 feet, and that of 38 [would become] of 42; by enlarging them, which is unavoidable, they would become weak to an extent that any little force or any augmented number of people would break them [...].
>
> I leave aside [the fact] that any storm of the sea and any little effort to which they would be subject would break them entirely into pieces. If one now wants to have them cut of such length in the woods of the Archdukes, one would have to have them kept thick and heavy to such an extent that neither only 4 men nor even six would be able to employ them either for a long or for a short [time]. (GO TO FOLIO)

40. CONTARINI, *Fabrica di galee*, cit., 9v.

Proto of the Venetian Arsenal. Vecellio C., *De gli habiti antichi, et moderni di diuerse parti del mondo libri due, fatti da Cesare Vecellio,* […], Venetia, Presso Damian Zenaro, 1590.

Balbi is evidently referring to the fact that oars which are enlarged by only about the per cent of their length would nevertheless, in order to preserve their stability, have to be of such a thickness that their mass would disproportionally increase to the extent that the usual number of oarsmen would no longer suffice to move them.

His judgement is shared by other craftsmen, among them Christoforo de Zorzi, the *Proto* of the oarsmen:[41]

> Your excellent Sirs having ordered me, Christoforo de Zorzi, *Proto* of the oarsmen, that I tell you my opinion whether, when making galleys that are larger than the present ones, this will be of greater service, I tell you respectfully that, making them larger, the oars have to be of greater length, and as the oar will be longer, it will have no force because it will be fragile and will have the consequence that the oarsman cannot row because the handle will strike him in the breast. (GO TO FOLIO)

Driven by an imminent technological challenge, these practitioners thus clearly articulated the problem of the relation between scale and fragility which is at the center of Galileo's new science of materials, without, however, providing either quantitative rules or explanations for this relation.

An explanation can be obtained when the balance-lever model as it was employed by Galileo in his letter to Contarini is not applied to the problem of the propulsion of a galley but to that of the fragility of its oars. This novel application can be achieved by assimilating a different type of empirical information to one of the slots of the model. In fact, in his letter to Contarini, Galileo had considered the oar as a lever whose one end is, under ideal conditions, firmly stuck in the sea, considered as a solid substance, while the moving force acts at the other end. From this perspective, fulcrum and resistance coincide, "il medesimo sia sostegno et resistenza"[42], in Galileo's words. As an answer to Contarini's question this made little practical sense. But if now the effect of the force is not identified with the propulsion of the vessel but with the breaking of the oar, the presuppositions for conceiving the model of the cantilever beam, central to Galileo's theory of the strength of materials, are given. In summary, the technical challenges of building larger galleys evidently suggested a modification of the balance-lever model which turns out to be the key idea at the core of Galileo's theory of materials.

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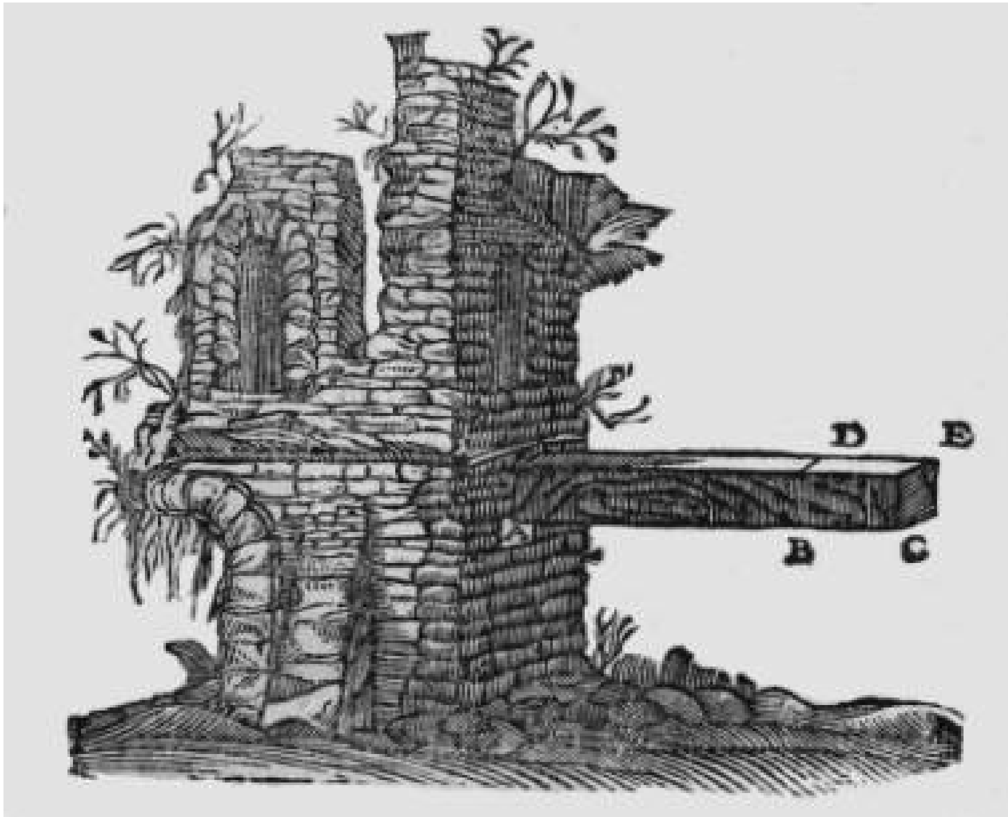
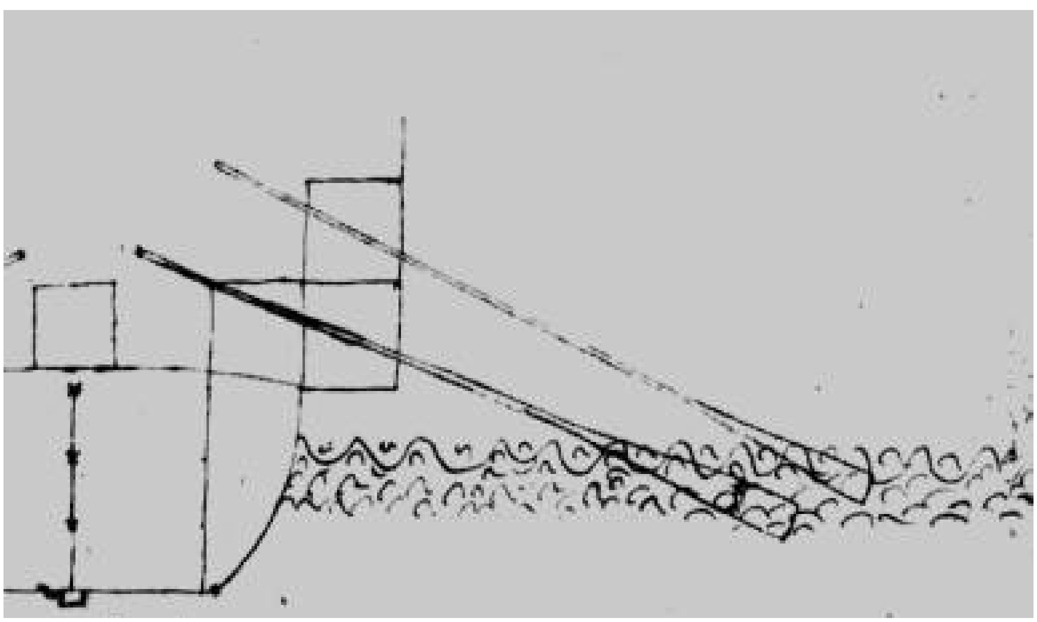
41. CONTARINI, *Fabrica di galee*, cit., 4v.
42. Galileo Galilei to Giacomo Contarini in Venice, March 22, 1593, in GALILEI, FAVARO (ed.), *Le opere di Galileo Galilei*, cit., Vol. X, n. 47, p. 55.





Galileo's cantilever model and detail of a study for the construction of a large galley with two oars per bench. Galilei G., *Discorsi, e dimostrazioni matematiche, Intorno à due nuoue scienze, Attenenti alla Mecanica, & i Mouimenti Locali*, Bologna, Per gli HH. del Dozza, 1655; Picheroni A. et al, Mss. it. VII, 379 (7588), Venice, Biblioteca Nazionale Marciana, XVI century.

Conclusion

We have thus shown that also Galileo's first new science, that of the strength of materials, was based on practical knowledge. The reinterpretation of a traditional mental model of mechanics, triggered by a problem encountered in the Arsenal, has turned out to be the essence of the innovation represented by Galileo's science of materials, whose deductive consequences resulted from the fact that the balance-lever model was already part of an elaborate theoretical tradition of mechanics. Practical knowledge, on the other hand, entered the origin of Galileo's new science not as providing raw data but was itself already structured by mental models such as those guiding the qualitative reasoning of the craftsmen with regards to the relation between scale and fragility.[43]

Beyond the reconstruction of the practical origin of Galileo's new science of materials, our glimpse at the Arsenal opens yet another perspective on the relation between early modern science and practical knowledge, regarding the social history of this relation. We have earlier raised the question of whether it is conceivable that the *Discorsi* could have been written by a *Proto*. Given the nature of practical knowledge this seems unlikely. As a matter of fact, such knowledge is traditionally transmitted by participation and oral transmission only and is largely independent of written representations. Practical knowledge thus neither generates theory nor requires it. We have seen, on the other hand, that in the context of Contarini's activities, not only was a written documentation of practical knowledge actually produced, but the practical problems of the Arsenal were also brought into contact with theoretical knowledge. We have also seen that this was not an individual predilection of Contarini but the consequence of the institutional setting under which he acted. He played the role of a mediator between politically and militarily motivated technical challenges and the practical and theoretical possibilities to realize them, represented by the testimonies from various sources he collected.

The rapprochement of practical and theoretical knowledge was a generic consequence of the great technical ventures of the Renaissance and of the early modern period, where specialized experts gained technical knowledge that would never have been available to single artisans. These ventures confronted early modern science with an intellectual provocation represented by a new range of experiences that triggered the exploration of

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43. We have begun to reconstruct the mental models of the practical knowledge of shipbuilding as well as their dependence on specific working tools and experiences of the practitioners by analyzing still-existing traditional technologies such as the construction of gondolas in Venice. A preliminary report is to appear as a Preprint of the Max Planck Institute for the History of Science.

the limits of traditional conceptual frameworks such as Aristotelian natural philosophy and ancient mechanics. But this rapprochement of practical and theoretical knowledge was not an encounter between mutually extraneous worlds. As we have seen, the great enterprises were themselves embedded in a social fabric that generated reflections on practical knowledge and also offered the social positions for those who, like Contarini, were charged with the intellectual dimension of the great practical challenges. This is true not only for Contarini but also for other figures such as Brunelleschi directing the grand building site of the cupola of *Santa Maria del Fiore* in Florence, whose sophisticated administrative structure is recorded in the collection of the *Opera del Duomo*.[44]

Brunelleschi, Contarini, and Galileo formed part of a class of administrators-engineers-scientists whose social role had emerged in the rising cities since the late Middle Ages, along with the knowledge resources at their disposal. As a matter of fact, a conspicuous technical, administrative, and logistic know-how had been accumulated over generations in the ever more powerful governments of independent cities such as Venice and Florence. The great ventures of the Renaissance and the early modern period thus brought about, at the same time, new practical knowledge as well as a new type of intellectual, who, in the realization of these ventures, drew on all bodies of knowledge available to them.

This knowledge comprised also the theoretical traditions of ancient science. The circumstance that this knowledge was, in contrast to the situation of ancient cities, not separated from artisanal and technical knowledge turned out to be a crucial prerequisite for the great engineering ventures of the Renaissance and provided the presupposition for the encounter between theoretical and practical knowledge in early modern science. Galileo's visits to the Arsenal were hence not the Sunday outings of a bored theoretician but the return of an engineer-scientist to the roots of his knowledge and of his social position. What contribute to his greatness and often overlooked by those who prefer to see him as a man essentially without past and predecessors, is that he was aware of these roots.

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44. This collection, transcribed and analyzed by Margeret Haines and her collaborators, has recently been made available on the Internet in the context of a project by the Max Planck Institute for the History of Science realized by Jochen Büttner. The collection is freely accessible from the website of the *Opera del Duomo*, http://www.operaduomo.firenze.it/ or from that of the Max Planck Institute for the History of Science, http://www.mpiwg-berlin.mpg.de/.

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