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Galileo's *La bilancetta*: The First Draft and Later Additions

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Résumé : Cette étude montrera que la confirmation expérimentale des conjectures constituait chez Galilée l'objet d'un souci constant, et ce dès le début de son activité scientifique. À l'appui de cette thèse, je citerai ses premiers travaux expérimentaux et montrerai avec quelle profondeur il était capable d'analyser par lui-même ses résultats. Je démontrerai ensuite qu'il a discuté de ses résultats avec d'autres scientifiques afin de confirmer ses intuitions initiales. C'est en les consultant et en bénéficiant de leurs conseils qu'il put mener ses intuitions à leur état final.

Abstract: This study aims to show that the experimental confirmation of his conjectural ideas was a constant concern for Galileo from the very beginning of his scientific activity. In order to support my view, I shall quote his early experimental work and first show the extent to which he was able to analyse his results in depth by himself. Then I shall give evidence that he discussed his results with other scientists to help confirm his initial intuitive ideas. He consulted with them and their advice helped him to come to his final conclusion regarding his insight.

1 Introduction

Albert Einstein called Galileo Galilei “the father of modern physics and in fact of the whole of modern natural science” [Einstein 1933, 164]. He justified his judgement with a rather shocking statement: “pure logical thinking can give us no knowledge whatsoever of the world of experience; all knowledge about reality begins with experience and terminates in it”. Indeed, this is what Galileo is credited to have done. This study aims to show that the

experimental confirmation of his conjectural ideas was a constant concern for Galileo from the very beginning of his scientific activity. In order to support my view, I shall quote his early experimental work and first show the extent to which he was able to analyse his results in depth by himself. Then I shall give evidence that he discussed his results with other scientists to help confirm his initial intuitive ideas. He consulted with them and their advice helped him to come to his final conclusion regarding his insight.

2 Preliminaries

Galileo's approach to *philosophia naturalis*¹ was the following: he strongly believed that Nature is the work of God and only needed a correct interpretative approach to be fully understood. Moreover, he thought that the scholars he called "filosofi *in libris*" [Galilei 1890-1909, XI, 11-12, hereafter OG], did not have the correct approach in basing their understanding on reading Aristotle's scientific books.² Rather, he believed that the correct interpretation of a natural fact should stem from direct, close observation and from well-planned and carefully performed experiments to verify it. Finally, he believed that a true scientist should be able to work out the collected evidence "in lingua matematica, e i caratteri son triangoli, cerchi ed altre figure geometriche, senza i quali mezzi è impossibile a intenderne umanamente parola; senza questi è un aggirarsi vanamente per un oscuro laberinto"³ [OG, VI, 219]. In fact, Galileo drew the best from the books of Euclid, Archimedes and other ancient mathematicians,⁴ whose greatness he could fully appreciate. However, he constantly favoured exploring "questo grandissimo libro, che essa natura continuamente tiene aperto innanzi a quelli che hanno occhi nella fronte e nel cervello"⁵ [OG, XI, 109]. In other words, he pushed himself to engineer new experiments that mimicked and explained what he could directly observe in

1. At that time, one would call *philosophia naturalis* (= natural philosophy) the entire scientific knowledge of the Earth because nobody had yet had the idea that making artificial materials was possible. God had created everything from chaos.

2. These include both Aristotle's original or attributed Greek works and also all interpretations by his followers, spanning from the peripatetic school to the scholastic one which takes into due consideration the Islamic interpretations available in Latin translation. Galileo was careful not to mention the Bible in this context but could not avoid involving it implicitly.

3. "In the language of mathematics, the characters of which are triangles, circles and other geometrical figures; without these it is impossible for a man to understand a word; without them it is like roaming in vain through a dark maze." All translations from Italian are by me.

4. He knew only those translated into Latin and Italian, as well as their medieval and Renaissance comments because his knowledge of Greek was only "non mediocre" (= just ordinary) [Viviani 1674, 2], [OG, XIX, 601].

5. "This very large book which Nature itself constantly keeps open in front of those who have eyes on their forehead and in their brain."

the surrounding world before applying mathematics to their interpretation. Moreover, his statement above also clarifies the fact that he felt a definite separation existed between the simple observation of natural events through sight and the understanding thereof conceived in and by the brain. Valuable results could only be achieved when scientific observation and technological experience were directly combined. He began practicing science in this way as early as in his youth [Fredette 1972], [Drake 1978, 1986], around the time when he started his training at Florence's newly founded Accademia delle Arti del Disegno, an institution whose purpose was to link science concepts to engineering practices. There, he met some of the best mathematicians, natural scientists and technologists of late Italian Renaissance and became confident in considering nature as just one of the two means chosen by God to display his immense power. The result of this form of training was the development of the approach that has only recently been named "technoscience" [Gorokhov 2015]. In Florence at the age of 22, Galileo gave the first demonstration of his new ideas on how to practice science, i.e., his first demonstration of what we would now call "technoscience". He wrote a short essay on a new method of using scales that is now entitled *La bilancetta* (= The little balance) [OG, I, 215–220],⁶ and used this instrument to make measurements of selected metals and gemstones.

This whole way of thinking was already rooted in Galileo's mind long before he made it clear in his famous "theological letters", i.e., the two letters he wrote to his pupil Benedetto Castelli on December 21, 1613 [OG, V, 282–288] and to grand-duchess Cristina di Lorena on June 1615 [OG, V, 309–348]. In both those letters, Galileo claims that God makes his work known to man using two equal sources of evidence—the Bible and nature. The Bible had to be interpreted by a human language and obviously, as a pious Catholic, he meant Latin. This often makes God's words difficult to grasp and easily misunderstood. The evidence inherent in nature must derive from data obtained through laborious observations and planned experiments which need to be supported by a skilled use of mathematics. Therefore, the path towards understanding which proceeds through science can never fail because

6. According to Vincenzo Viviani, Galileo's last pupil and the collector of most if not all his papers, he wrote this essay in 1586 [Viviani 1674, 9], [OG, XIX, 605]. Stillman Drake challenges this dating which is given in a marginal note added to a letter by Viviani to Cardinal Leopoldo de' Medici on April 29, 1654. He supports his challenge [Drake 1986, 437–439] by citing the watermark on a paper sheet near the end of the unfinished dialogue *De motu*, which is bound in the same volume just before *La bilancetta*. This watermark could show that Galileo wrote the dialogue on sheets acquired while teaching at Siena during the 1586–1587 academic year. In such a dialogue, Galileo refers to have recorded previously two sets of measurements of gold-silver alloys by the hydrostatical method. Drake infers from this that Galileo wrote *La bilancetta* later than those measurements namely when he had left Siena in late spring 1587 and moved back to Florence. Notably, Drake contradicts himself in the table that follows at p. 440: there, he lists *La bilancetta* as written at Florence in 1586 and the dialogue *De motu* at Siena in 1586–1587.

it consists of logical figures. Galileo's juvenile writings have fortunately been preserved in the Florence National Library and they provide excellent proof on how early and firmly he adopted this belief [Fredette 1972], [Drake 1978, 6–7], [Camerota 2004, 45–48], [Gorelik 2012], etc. In particular, *La bilancetta* is the first of Galileo's writings in Italian, the language in which could best express his ideas, and thus deserves detailed study.

3 The edited text of *La bilancetta*

La bilancetta was Galileo's first original full scientific essay but it is also a very innovative text because it alone enabled him to open up a new approach to upgrade hydrostatics and make it a method for studying solid matter. His innovation occurred almost two millennia after Archimedes of Syracuse had laid the fundamentals of that branch of Physics.⁷ Therefore, it was a real misfortune for the development of philosophy of science that most historians underrated *La bilancetta* for a variety of reasons:

1. It is a minor contribution to science, when compared to the later novelties on astronomy and general physics that made Galileo foremost among contemporary scientists.
2. The fact that it is in Italian could perhaps suggest that the author himself did not consider it worthy of particular attention. Indeed, at that time, high-quality scientific papers were written in Latin to reach the largest possible audience within the scholarly community. Galileo was an exception but he too often agreed to do so.
3. It is the work of a youth who was not yet completely trained. Galileo had written it after leaving Pisa University without a degree and before meeting Guidobaldo del Monte who he could have consulted on the mathematical aspects of the subject.
4. It contains the description of a long-known instrument, which he used without introducing any special modifications. Even the weighing system is the usual one. He just operated using a sequence of steps which made the new results possible.

7. Marcelin Berthelot had a completely different idea [Berthelot 1891, 477–481]. To his mind, Galileo had invented nothing new but only taken advantage of a long tradition. He supported his evaluation by referring to what is reported in the pseudo-Priscian (4th–5th century), in *Mappae clavicula* (an anonymous treatise he believed to be of 12th century) and in Heraclius (13th century). Conclusively, he argued that “l’emploi de la balance hydrostatique pour analyser les alliages d’or et d’argent repose sur une tradition certaine [...] transmise au Moyen Âge depuis le temps des Grecs et des Romains” [Berthelot 1891, 481] (= the use of hydrostatical balance for the analysis of gold and silver alloys is based on a solid tradition [...] that Greeks and Romans had transmitted to the Middle Ages).

5. Finally and most importantly for science historians who consider experimental results a priority, the essay apparently does not contain data which supports its conclusions.

The last prejudiced view is definitively wrong. The table of weights in air and water which Galileo used did exist but it was not known to most early science historians [Berthelot 1891]⁸ because the autographs were recognized and published only after two and a half centuries by a local academic journal [Favaro 1879]. By contrast, the text of the essay had its *editio princeps* just after Galileo's death. It appeared first as an extensive quotation hidden in a book published by another author [Hodierna 1644, cc. 2A1–8A]. However it was well known to Galileo's followers and was sent to press under his name some ten years after the *editio princeps* in the first print of Galileo's selected works which appeared at Bologna in 1656. Indeed, the title *La bilancetta* (although circulating before as the nickname for the apparatus) was chosen for the essay by Carlo Manolessi, the curator of the Bologna edition. The fact that Galileo⁹ had neglected to give a title to the essay would possibly indicate the minor importance he himself accorded it with respect to others later but he never refrained from distributing copies of it to his visitors while confined at Arcetri.

After having considered all those objections, I reached the conclusion that the autograph and all the contemporaneous copies of *La bilancetta* were worth direct and careful analysis. I did this to both edit the essay in a better form which corresponds to the original text Galileo had in mind¹⁰ and also to better understand the conceptual framework developed by the young Galileo. Indeed, all handwritten versions are worth studying closely in all their details right up to their last words since the essay chronologically precedes the full development of the epistemological thought of a “father of modern Physics” or in fact of “the whole of [...] modern science” [Einstein 1933, 164].

4 The first draft

Volume 45 of the collection “Mss. Galileiani” kept in the Biblioteca Nazionale Centrale of Florence (BNCF) is titled “GALILEO | GALLEGGIANTI | E | BILANCETTA | P. II. T. XVI” and contains most of the handwritten texts

8. Positively, Galileo's table on weights in air and water was unknown to Richard Davies, who assembled all data available in literature from Francis Bacon's time to his own [Davies 1748]. It was also unknown to Mathurin-Jacques Brisson, who measured the specific gravity of over 5000 materials [Brisson 1787].

9. As Hodierna also did in the *editio princeps*. However, in the long title given by Hodierna, he makes it clear that Galileo himself had called “bilancetta” the new instrument he had invented [Hodierna 1644, 1].

10. Which I did, by producing an updated diplomatic edition of all the texts mentioned here [Mottana 2016].

I intend to analyse in detail. The best-known one is “manuscript G”, which consists of a single, large sheet of paper (c. 55), 281 × 205 mm in size, densely written on both sides. It shows a small, rather crude drawing on top of the *verso* depicting the essential features of a balance or scales. Shortly after the pages in the volume were numbered in pencil by Atto Vannucci, the BNCf librarian from 1862 onwards [Procissi 1959, 119], a clever binder made this lone sheet conspicuous because he enclosed it between two cardboard sheets for protection. Then, some years later, Antonio Favaro ascertained that the handwriting of G was Galileo’s own [OG, I, 234] and the national edition which he later managed took this for granted. All subsequent scholars of the work also subscribed to this palaeographic identification [Procissi 1959, 119], [Crombie 1975, 157–175].

In continuation, volume 45 contains a clean copy of the same text, named “copia A” by Favaro [OG, I, 210–220] and written on cc. 56r–58r. These sheets are definitely not in Galileo’s handwriting [OG, I, 212]. Isidoro del Lungo, Gilberto Govi and Umberto Marchesini, the three philologists who helped Favaro edit the first volume of Edizione Nazionale—the time-table of all surviving writings by Galileo and his relations [Castagnetti & Camerota 2001, 359–361]—believed A to be coeval to G. Moreover, they also believed that A was the archetype for the copies Galileo distributed to his followers and this despite another copy (C) existing which might appear more authoritative because it is written by Vincenzo Viviani, Galileo’s last pupil and the first careful collector of most of Galileo’s writings and books.

Copy A is followed by a numbered but blank sheet (c. 59) and then another script closely related to the same subject, titled

Tavola delle proporzioni delle gravità in specie de’ i metalli e delle gioie pesate in aria, et in aqua. (cc. 60r–62r)

This kind of table is inconspicuous within volume 45 because it is just at the end of it and looks like a bunch of sheets containing random numbers which could have been used by the binder to buffer the binding. Favaro deserves further credit for recognizing the relationships between their content and the text of *La bilancetta* [Favaro 1879]. Later, he published the *Tavola...* following the philologically reconstructed version of the main essay [OG, I, 224–227]. However, nobody took much notice of this list of 39 metal and mineral names added with numbers written in the fractional form used at Galileo’s time. Only a German doctorate student, Heinrich Bauerreiß, mentioned the table in his dissertation [Bauerreiß 1914, 62–64] and realized that he could calculate the specific weights from Galileo’s given weights in air and water. Nevertheless, he did not try to interpret their meanings.

The interpretation of Galileo’s experimental weights in air and water was not carried out for another century. I made this interpretation both for gemstones (“gioie”) and for metals (“metallic”), with reference to the data printed in the Edizione Nazionale [Mottana 2014, 24–31], [Mottana 2014–2015, 187–241]. However, I later realized [Mottana 2016] that the original,

handwritten *Tavola*, like the current text of *La bilancetta* itself, consists of two parts. The first part is a partial clean copy written in smooth-running, accurate but unknown handwriting. It begins with the afore-mentioned title and lists eight measurements covering *recto* and *verso* of one sheet (c. 60). The following two sheets are an untitled sequence of words and numbers scribbled in Galileo's own handwriting (cc. 61r-62r) and list the weights of several metals and gemstones measured in air and water. On these sheets, somebody (probably the unknown copyist) ticked off the eight items listed in the clean copy, i.e., on c. 60. Thus, there is no doubt that this second section is Galileo's original working draft and the first section of the *Tavola*, including the long title, is a partial clean copy of it made at an undefined moment but certainly later than the experimental session.¹¹

To conclude, then, given the unequivocal evidence of what is signed and what is not, we can distinguish two time-sections in the composition of *La bilancetta*. There was an early, rough section (G: comprising cc. 55, 61 and 62) which was handwritten by the young Galileo. This was followed by a clean copy in unknown handwriting but which contains interesting additions that we assume to have been devised by Galileo after consulting his mentors (A: cc. 56, 57 and 60).

Reading c. 55, i.e., the hastily written first draft of the essay is not a big problem. Actually, G shows numerous word abbreviations of all types, including tachygraphic symbols and special graphs inherited from the Middle Ages (e.g., $\bar{o}$, $\bar{a}$, $\bar{u}$ for on, an, un; p for per; peh for perché; dūqj for dunque; arch.^{de} for Archimede, etc.) and has no capital letters anywhere. However, the *ductus* is always easy and there is no attempt at cryptography. Galileo was writing for himself, putting his ideas down with no restraint whatsoever as he did not intend to divulge what he was devising. Ideas were popping up freely in his mind and he put them down on paper just as fast as they came. Therefore, he used the sheet of paper that he had available in the most condensed way he could—cutting words, mostly using standard abbreviations, even omitting vowels, sometimes. At the end, to show that he had written all that he had in mind at that moment, he shortened a word he had frequently spelled out before either in full (argento = silver) or cut in the usual way (arg:). He used a semicolon (arg:). To my understanding, this very unusual abbreviation—Galileo uses it nowhere else—is a clear indication that he had reached the end of the topic or of his reasoning thereon and of the entire essay rather than just the individual sheet of paper. Yet, copy A continues for

11. Drake points out that sheets 60–62 have a watermark (a circled rooster or basilisk), which is “undoubtedly Florentine”. Based on this, he specifies “a dating of 1585–1586 that implies priority with respect to *La bilancetta*” [Drake 1986, 437]. I could not verify this information, and, in particular, whether the watermark is located in cc. 61–62, handwritten by Galileo, or in c. 60, which the copyist wrote. Nevertheless, I strongly doubt that Galileo performed the experiments before writing his theoretical essay, which shows all evidence of being an *ex abrupto* script.

several lines and consequently Favaro believed that G is a surviving fragment from a longer paper. I should like to suggest another possibility.

5 The additions

Galileo wrote his essay as a youngster, when he was a student in Florence Academia. Cosimo I de' Medici created this school to supply his newly granted Duchy with technically trained architects, engineers, gunners and so forth. The teachers were some of Florence's best technicians and scientists. Furthermore, occasionally, certain scholars who were qualified at university level (but who had not continued their career in universities) taught at the school. One of them was Ostilio Ricci, a friend of Galileo's father Vincenzo, who was the man who had enabled Galileo to enter the academic world. Ricci was not a university man but was nonetheless among the best teachers of mathematics of his time. He himself had been the pupil of the very best teacher—Niccolò Fontana called Tartaglia (= the Stutterer), another exceptionally gifted man who had been rejected by learned society because of his speech defect. Ricci gladly advised Galileo about mathematical problems.

Another academic who was even better disposed toward Galileo was Guidobaldo del Monte, a nobleman who had studied mathematics at Urbino in the private advanced school set up there by Federico Commandino, the famous humanist and mathematician who had edited the Latin translation of Archimedes' works. Guidobaldo had not continued with a university career because it was inadequate to his high social rank and also because he preferred the practical application of mathematics (particularly ballistics) to developing abstract concepts. He was a technologist with strong mathematical basis, a “technoscientist”, if we use a modern word [Gorokhov 2015]. He often lived in Florence because he was the Chief Officer for Fortifications of the entire Duchy. Guidobaldo became acquainted with the young Galileo, found him to be a clever pupil, invited him to his mansion near Urbino and exchanged letters and discussed problems with him for several years.

During the 1587-1592 period, Guidobaldo was noting down theorems and ideas at random in a bulky manuscript titled *Meditationumculae de rebus mathematicis* (= Small meditations on mathematical matters).¹² Like most learned men of his time, Guidobaldo wrote his notes in Latin. Therefore, it comes as a surprise to read a sentence in Italian following a long Latin evaluation of how the lever rule applies to a balance (cc. 232–234) [Tassora 2001, 540–543]. This sentence is written in a smaller character and with different ink but is clearly in Guidobaldo's handwriting, and tells:

12. This manuscript is in the Bibliothèque nationale de France in Paris (*Ms. latin 10246*). Roberta Tassora transcribed and commented on it in her unpublished dissertation which is in open access online [Tassora 2001].

Potrà forse accadere, che *np*, *pl* uenghino linee tanto piccole, che non si possi comodamente trouar la loro proportion. Et però si potrà pigliar il punto *q*, doue si voglia, e tirar le linee *qnr*, *qps*, *qlt*, e tirar la linea *rst* parallela a *npl*, che hauerà *rs* à *st* la medesima proportion, che ha *np* à *pl*. Poi si potrà pigliar un bastone dritto, et avvolgergli attorno una corda di citara ben sottile, e che le spire si tocchino l'una l'altra, che per esser pari, si potrà ueder quante spire siano *np pl*, ouero *rs st*. E così, quanto comporta l'atto pratico, si hauerà in numerj la proportion dell'oro e dell'argento della magnitudine di *ac*.¹³ [Tassora 2001, 543]

The first lines of this passage are a rigorous mathematical demonstration explaining a figure not reported here which Guidobaldo had carefully drawn using square and rule on the top part of the sheet. The final lines are of no mathematical interest and are not particularly rigorous either. Guidobaldo describes a practical method to make rapid but rough measurements of the ratio between gold and silver in a mix. This script is valuable however because it refers to the same method as that set out in G, the first draft handwritten by Galileo. Thus, it was Galileo who had the idea of making a wire coil around one arm of the balance and Guidobaldo simply corroborated the idea in his statement using more or less the same words as Galileo. However as a pure mathematician, he does not bother with technical peculiarities such as using two different kinds of metal wires to speed counting up as Galileo suggested in the last lines of his manuscript G.

The sentence mentioned above by Guidobaldo is of dual historical importance.

1. It corroborates Viviani's [Viviani 1674] idea of dating *La bilancetta* to 1586, a year that a number of critics [Crombie 1975, 167], [Settle 1983] have suggested to be too early in the development of Galileo's scientific thought. In fact, we can be sure that Guidobaldo wrote his *Meditatiunculae* after 1587, when he released his main work commenting on Archimedes' hydrostatic essays for printing and received the handwritten notes of his teacher Commandino on Pappus' work [Tassora 2001, 36–38] and before 1592 at the latest, when he finished an essay

13. "It could possibly happen that *np*, *pl* became lines as small as not make it easy to find their proportion. One could then project from a point *q* anywhere and draw the lines *qnr*, *qps*, *qlt*, and draw the line *rst* parallel to *npl*, which will have the same proportion *rs* to *st*, which *np* to *pl* has. Then, one could take a straight stick, and roll it up with a very thin guitar string so that the coils touch one other, and because they are equal one shall see how many coils are *np pl* and how many *rs st*. In such a way, in the short time taken by the operation, one will have in numbers, what the proportion of silver and gold will be in the bulk of *ac*". My translation should compare to what Cecil Stanley Smith wrote at page 140 of the Appendix concerning the structure of *La bilancetta* [Fermi & Bernardini 1961, 133–141]. Smith's translation, which is the only translation available in English, covers the entire passage as given by the official edition [OG, I, 217] which in turn mostly derives from copy A.

on prospectics [Tassora 2001, 42–44]. By contrast, for *La bilancetta*, the previous *ante quem* documented date is 1641, when Galileo wrote a letter presenting a copy of it among his works donated to the Polish Monsignor Stanisław Pudłowski (*rectius*: Stanisław Pułłowski) [Burattini 1675, 3]¹⁴ [Tancon 2006, 112–115]. Alternatively and by inference only, other scholars have suggested the composition of *La bilancetta* to be around 1611–1612 when Galileo argued bitterly with the Florentine Aristotelians and used similar arguments to contrast them effectively in his *Discorso al serenissimo don Cosimo II. Gran duca di Toscana Intorno alle cose, che stanno in su l'acqua, ò che in quella si muouono*. The *Discorso* [...], which he printed twice in 1612 with a few minor changes [De Salvo 2010, 83–153], is the cornerstone of Galileo's conceptions on hydrostatics and takes the slim book on the little balance into full account although it never mentions the experimental data from the *Tavola*. Hence, the text of *La bilancetta* should predate the *Discorso* [...] by some years. By inference, it also suggests the possible composition of G before 1587–1592.

2. It shows that Guidobaldo, one of the most brilliant mathematical minds of his time, had taken the young Galileo's problem very seriously. He provided the correct mathematical solution [Tassora 2001, 543] and also actually adopted the instrumental set up that would make the little balance a rapid and effective tool to measure the proportion of gold to silver in a mix even though he does not mention the other practical advice contained in the last lines of G.

That is enough regarding the main text. However, copy A, from which most printed editions of *La bilancetta* derive, contains the description of another technical operation which is most practical to speed up counting but also so simple as not to appear even worth mentioning by Guidobaldo. Galileo may have considered it inappropriate to submit it to him for his support as there is nothing mathematical in this operation. It consists of rubbing a thin “stiletto” (= stylet) above the coils to count them by the sounds made because of the contrast between metals [OG, I, 220 ll. 4–18]. We should consider it a bold suggestion which probably derived from Galileo's deepest memories of teaching from his father Vincenzo, a musician, unless Vincenzo himself directly suggested it (he was still alive at that time).

Galileo's good ear for music made him an excellent lute player [Viviani 1674, 2], [OG, XIX, 601] and therefore we cannot wonder if he proposed a sonic method to count the coils in order to determine the gold to silver ratio. Instead,

14. Burattini testifies that the Monsignor allowed him to see the copy in 1642. He made use of this copy in an essay titled *La bilancia sincera [...] con la quale per teorica e pratica con l'aiuto dell'acqua, non solo si conosce le frodi dell'oro e degl'altri metalli, ma ancora la bontà di tutte le gioie e di tutti i liquori*. This essay, written in 1645, was never printed but survives as a manuscript in the Bibliothèque nationale de France (*Mss. Ital. n. 448, Suppl. fr. 496*).

it is legitimate to wonder when he added this operation to G, as it first occurs in copy A and in all other surviving handwritten copies. If Vincenzo suggested it to him, this would have occurred before July 2, 1591 when Galileo's father died in Florence. Otherwise, we could consider any time before 1612 when Galileo had to reconsider all his ideas on hydrostatics because of the quarrel he had with the Florentine Aristotelian scientists [De Salvo 2010].

There were also at least three instances when he had the chance to rethink his early work on hydrostatics.

In 1597, while a professor in Padua, Galileo devised a proportional compass, called "compasso geometrico et militare" (= geometric and military compass), which made it possible to rapidly perform all calculations needed by practical stoneworkers, land-surveyors, moneylenders, gunners, etc. [Drake 1977, 35–54], [Camerota 2004, 124–129], [Bertoloni Meli 2004, 166–169]. He had a number of such compasses built by an artisan, Marcantonio Mazzoleni, and made good profit by selling them. When the popularity of the instrument grew to the point that he could no longer personally teach all buyers how to use it, in August 1606 he wrote a handbook titled *Le operazioni del compasso geometrico e militare* [OG, II, 363–424], had it printed privately and started distributing it together with each new compass he sold. Among the seven proportional scales drawn onto the compass made up of two movable brass rulers (four on the *recto* and three on the *verso*), the outermost one concerns the proportionality existing between pairs of seven materials (gold, lead, silver, copper, iron, tin, marble and stone), each of them marked as a point on both rulers. Chapters XXI–XXIV of the handbook explain how to operate the compass. With the two rulers set at any opening, the intervals between any correspondingly marked pair of points give the size of spheres (or of other solid bodies such as cylinders and cubes) which are similar to each another and equal in weight. In other words, the compass solves the calculation that arises when comparing materials of different specific gravity, irrespective of whether this is determined hydrostatically or by dividing the weight of the corresponding sphere, cylinder, or cube for its volume.¹⁵

Galileo had other chances to rethink hydrostatics, because his ideas were subject to the envy that always surrounds a successful scientist in the university world.¹⁶ Less than six months after his handbook on his compass

15. The developer, if not the inventor, of this purely geometric method was Marino Ghetaldi, from Ragusa in Dalmatia. He published it in 1603 in a book titled *Promotus Archimedes seu de variis corporum generibus gravitate et magnitudine comparatis* [Napolitani 1988], [Bertoloni Meli 2004, 168–170]. Galileo and Ghetaldi met, possibly in Rome in 1600 and certainly in Padua in 1607. They exchanged letters for several years.

16. He speaks of "false imposture [...] fraudulent inganni [...] temerari usurpamenti" [OG, II, 518] (= false imposture, fraudulent deceits and reckless usurpations). I am currently studying the happenings related to the compass affair within the framework of Galileo's attempt at creating a factory of scientific instruments in Padua.

appeared, Baldassarre Capra, a former pupil of him, translated it into Latin [OG, II, 425–511] and attempted to claim the invention as his own. This compelled Galileo to take legal action against him (which he won in April 1607) and to act firmly to protect his own reputation. He also did this by writing a pamphlet [OG, II, 515–599] which however adds nothing to the scientific question. Thus, we find no further clues about when he added the sound method to measure the gold to silver ratio in copy A of *La bilancetta*. Possibly, the emotional stress of his father’s death may have led Galileo to propose such a peculiar idea.

6 Final remarks

La bilancetta never mentions the measures reported in the *Tavola*, not even as a simple reference. Similarly, there is nothing about gemstones and metals in Guidobaldo’s *Meditatiunculae*. Possibly Galileo did not show Guidobaldo his measurements carried out in air and water or perhaps Guidobaldo simply did not consider them worth of his attention and thought them technically too low-level. In any case, *La bilancetta* referred to the reference works on hydrostatics without the support of all the experimental data that Galileo had made. That is possibly the reason why two and a half centuries passed before the significance of specific weight as a reliable indication to identify gemstones was recognized [Haüy 1817] and it took two more centuries before Galileo’s pioneering contribution to gemology was rightly acknowledged [Mottana 2014].

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