Weighing Experience: Experimental Histories and Francis Bacon’s Quantitative Program

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Abstract
Weighing of experience was a central concern of what Bacon called the “literate” stage of experimentation. As early as 1608, Bacon devised precise tenets for standard, quantitative reporting of experiments. These ideas were later integrated into his experimental histories proper. Bacon’s enquiry of dense and rare is the best example of experientia literata developed in a quantitative fashion. I suggest that Bacon’s ideas on this issue can be tied to experiments for the determination of specific gravities born in a monetary context: Bacon’s investigation was very likely a generalization of Jean Bodin’s experiments in Universae naturae theatrum (1596). Overall, Bacon’s program of quantification calls for a revision of established historiographical notions, especially Thomas Kuhn’s sharp dichotomy between a mathematical and a Baconian experimental tradition in seventeenth-century science.

Keywords
experience, experiment, experientia literata, natural history, experimental history, quantification, specific gravities, Jean Bodin, Gerard Malynes, François de Foix de Candale, Thomas Kuhn

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1. Introduction: “History Mechanical” and *experientia literata*

In Francis Bacon’s philosophy of experiment, proper recording of experience acquired a paramount role. For Bacon, the composition of experimental accounts was an integral part of the experimental process: experimental activity ended only when experience was reported and written down. The locus classicus of this conception can be found in aphorism 101 of Book I of *Novum Organum*:

> So far mental effort has had a much more important part to play in discovering than has writing, and indeed experience has yet to be made literate. And no discovery should be sanctioned save that it be put in writing. Only when that becomes standard practise, with experience at last becoming literate, should we hope for better things.¹

Experience finally “becoming literate,” or *experientia literata*, provided the correct material for natural and experimental histories, the proper basis out of which to build natural philosophy and reach the higher philosophical stages of Bacon’s New Organon.

*Experientia literata* also included an operational side. In *De augmentis scientiarum*, Bacon identified it with eight different “modes of experimentation,” rules of thumb through which new experiments and technical inventions could be devised and “translated” from previous, existing ones. A two-sided activity, *experientia literata* was at the same time concerned with the production of experiments and their presentation in structured, systematic accounts. However, experimentation reached its “literate” stage only if detailed in written reports. In this paper, I specifically concentrate on some features of this second aspect of *experientia literata*.²


²) On *experientia literata*, see the important articles by Lisa Jardine, “*Experientia Literata* or *Novum Organum*? The Dilemma of Bacon’s Scientific Method,” in W.A. Sessions, ed., *Francis Bacon’s Legacy of Texts* (New York, 1990), 47-67; Sophie Weeks,
Francis Bacon’s initial thoughts on the notion of *experientia literata* are intertwined with the plans for the preparation of a “mechanical history,” or history of the experiments of the mechanical arts. Already in 1605, Bacon stressed the importance of a “History Mechanical, … of all others the most radical and fundamental towards natural philosophy.” Such history, Bacon stated in *The Advancement of Learning*, will not only minister and suggest for the present many ingenious practices in all trades, by a connexion and transferring of the observations of one art to the use of another, when the experiences of several mysteries shall fall under the consideration of one man’s mind; but further it will give a more true and real illumination concerning causes and axioms than is hitherto attained.3

As he later explained in *Novum Organum*, this was in fact the prerequisite for the research program of *experientia literata*:

> When all the experiments of all the arts have been collected and arranged, and come within one man’s knowledge and judgment, many new things, useful to our life and condition, can be discovered by means of that very translation of experiments from one art to others, i.e. by that experience which I have called literate.4

An often-overlooked passage from *Commentarius Solutus*, Francis Bacon’s private notebook of 1608, clearly shows that Bacon’s thoughts on a “History Mechanical” also helped to shape his ideas regarding the sort of written reports necessary to render experience literate. In the *Commentarius*, Bacon laid down strict requirements on how to record information regarding the experiments of the arts. Bacon had in mind systematic statements in which to specify important aspects of a particular technical process:

> To procure an History mechanique to be compiled with care and diligence and to professe it that is of the experim[en]t and observations of all Mechanicall Arts. The

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places or things to be inquyred are; first the materialls, and their quantities and proportions; Next the Instrumt and Engins requeste; then the use and ad-operation of every Instrumt; then the woork it self and all the processe thereof w th the tymes and seasons of doing every part thereof. Then the Errors w ch may be comytt-ed, and agayn those things w ch conduce to make the woorke in more perfection. Then all observacions, Axiomes, directions. Lastly all things collaterall incid or intervenient.  

It is noteworthy that this scheme, initially conceived to describe the experiments of the arts in a “History mechanique,” will be used more generally as a template for the accounts of Bacon’s experimental histories. Bacon’s first attempt at one, the *Phænomena universi* of 1610-1611, already showed an arrangement that was clearly inspired by the model of the *Commentarius*. The *Phænomena* included detailed accounts of experiments, the “Historiaz,” which gave precise and quantitative information on the apparatus and the experimental process under consideration. Following the sketch of the *Commentarius*, together with the Historiaz Bacon included “Monita,” or suggestions for the improvement of experiments, and general observations (“Observationes”) with preliminary conclusions on causes. The *De fluxu et refluxu maris* of 1611 added to these elements the “Mandata,” or directions and prescriptions for future enquiries. In the *Historia naturalis et experimentalis* of 1622 Bacon was to employ all the practices already described in his plan of 1608. In the prefatory section titled *Norma Historiae presentis* he again highlighted the paramount role of “Historiaz” and experimental accounts. In accordance with his previous *Commentarius*, Bacon also included in his histories “advice and cautions about the fallacies of things, and the errors and snags which may crop up in the course of

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5) *Commentarius Solutus*, in Francis Bacon, *Works*, James Spedding, Robert L. Ellis and Douglas D. Heath, eds. (London, 1857–1874), 11: 65-66. (The Spedding edition has a single open bracket between ‘diligence’ and ‘and to profess’, which I have omitted). It is worthwhile to remember that Bacon related this project to that of the establishment of a college for inventors in the mechanical arts, a true laboratory and workshop in which to develop *experientia literata*; ibid., 66-67.

inquiring and discovering,” also incorporating personal interpretations, speculations, provisional rules and theoretical conclusions.

2. Recording Experience

However, the central and primary parts of Bacon’s accounts are the “Historiae” and descriptions of actual experiments. It is interesting to note that, in the Latin texts of the Instauratio, in order to refer to the thorough recording of histories, Bacon repeatedly uses the term “perscribere,” a verb that, in a dictionary of Bacon’s time, is translated as “to write through, or to an end: to write at length or at large: to register or to enroll.” In the Distributio Operis, Bacon restates his goal:

[to] record in detail [perscribimus] (as far as I have been able to investigate them, and as far as they contribute to my aim) all the experiments of the mechanical arts, of the operative department of the liberal arts, and the many practices which have not yet coalesced into a proper art.

To this, Bacon adds that

[in every new or slightly more subtle experiment, though (it seems to me) certain and proved, I still subjoin a clear account of the way I performed it, so that, after revealing its every detail, people can see if any latent fault clings to it, and push themselves to find (if any there be) more reliable or accurate proofs.]

In this context, the use of the verb “perscribere” is doubly significant. First of all, it is a term that has antecedents in the classical tradition of

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7) To stimulate “human industry,” among such observations Bacon inserted two new categories, namely the “Vellicationes de Practica,” or “incentives to practice” (these are added for “men’s attention and memory,” given that “I well know that such … is their stupidity that sometimes they do not see what is in front of their noses”), as well as the “Res impossibiles,” or “things deemed impossible” or at least “so far undiscovered.” Norma Historiae presentis, in The Instauratio Magna, Part III: Historia Naturalis and Historia Vitae, ed. Graham Rees and Maria Wakely; vol. 12 of The Oxford Francis Bacon (Oxford, 2007), 12-17.

8) Thomas Cooper, Thesaurus Linguae Romane et Britannicae (1584), in Lexicons of Early Modern English, ed. Ian Lancashire (Toronto, 2006). Online resource. (leme.library.utoronto.ca)


10) Ibid., 11: 41.
history writing, and was used for instance by Livy in his preface to the History of Rome, with the precise sense of a thorough record, a report written exactly and in its entirety, without the addition of personal interpretations.11 Secondly, the other connotation of the term – “to enroll” – suggests institutional and official reports.

In general, as he explains in Novum Organum, Bacon rejects previous natural histories as their accounts are not detailed and thorough enough. Further statements better qualify the type of completeness and thoroughness that Bacon has in mind. In these histories, “we find nothing … duly examined, verified, counted, weighed and measured.”12 In Parasceve ad historiam naturalem et experimentalem, Bacon compares these accounts with the proper way of collecting information:

I demand that every thing to do with natural phenomena, be they bodies or virtues, should (as far as possible) be set down, counted, weighed, measured, and defined [numerata, appensa, dimensa, determinata]. For we are after works, not speculations [Opera enim meditamur, non Speculationes], and indeed a good marriage of Physics and Mathematics begets Practice [Practicam].13

It is then clear that, in this respect, what distinguishes Baconian histories is the level of precision and accuracy to be reached. A fundamental way to achieve such detail is by means of quantification. “As far as possible [quantum fieri potest],” Bacon’s histories should be quantitative and aim at measurements. Among the “countless … instances” to be duly “investigate[d] in detail and thoroughly record[ed]” are astronomical measurements, geographical extensions, comparative weights and densities of metals.14 For instance, in the ‘History of Heavenly Bodies’, “we study the precise returns and distances of the Planets” with an eye to practical application in navigation; in the ‘History of the Earth and Sea’, the “extent of Rand”; in the ‘History of Air’, “how much

impression air will put up without strong resistance”; in the ‘History of Metals’, “how far one may outweigh another.” When such precise measurements are not achievable, at least we need to provide “rough estimates and comparisons.”

This quantitative experimental program is always connected to an operative dimension, and to the possibility of producing opera and originate “Practice.” Accuracy and quantification are necessary conditions to reach such aims, and past histories are useless and fail in this respect because they lack such qualities.

3. Weighing Experience

Bacon’s aim, then, is that of weighing and evaluating experience. This is a very important point, because Bacon’s setting down of experience “in writing” is not a generic process of textual recording. Not all experiential textual records are acceptable, but only those in which observations are rigorously evaluated and—as far as possible—counted, weighed, and measured. It is only this further stage of weighing and assessing that makes experience “literate.”

It is interesting to follow Bacon’s use of the Latin expression “pensitanda experientia,” which Bacon adopts to describe this idea. The verb “pensitare” can be translated as “to weigh, ponder, and consider often and diligently.” In his work Bacon uses the full range of connotations for this expression, from the metaphorical ones up to the literal, physical sense. So, for instance, in the dedicatory epistle of the Instauratio, Bacon invites King James to rival Salomon himself by giving start to a wide-ranging project for the “collecting and perfecting of a true and rigorous natural and experimental history,”

So that at last, after so many ages of the world, philosophy and the sciences may be no longer an airy and floating fabric but a solid construction resting on the firm foundations of well weighed experience of every kind [Experientiæ omni-genæ, … bene pensitatae].

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16) Ibid., 465.
17) Cooper, Thesaurus.
The weighing of experience is then the qualifying activity of proper natural history. In general, as Bacon states in *Novum Organum*, philosophy “rests on too narrow a basis of experience and natural history,” putting together few observations “neither securely established nor carefully examined and weighed.”19 Subtlety is vain, unless it is grounded on “weighing experience and thence building axioms.”20 The metaphor of weighing is at its strongest in a passage from aphorism 20 of book II, whose allusions to assaying are rendered correctly by Spedding:

And yet since truth will sooner come out from error than from confusion, I think it expedient that the understanding should have permission, after the three Tables of First Presentation (such as I have exhibited) have been made and weighed [factas et pensitatas], to make an essay [tentandi opus] of the Interpretation of Nature in the affirmative way; on the strength both of the instances given in the tables, and of any others it may meet with elsewhere. Which kind of essay I call the Indulgence of the Understanding, or the Commencement of Interpretation, or the First Vintage21

Now Bacon’s Interpretation of Nature, or the New Organon, is described as a form of assay, which needs to be preceded by the accurate and precise measurement of the instances and observations from the histories, properly measured and organized in tables.22

Not surprisingly, the rhetoric of a careful weighing of experience resurfaces in the discussion of the *Mathematical Instances*, or *Instances of Measure*, in book II of *Novum Organum*, where the verb “pensitare” acquires a more concrete nuance. These instances, Bacon states, are related to the effective achievement of operation and work. In general, “operation lets you down … by inaccurate determination or measurement.”

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20) “in pensitanda Experientia & inde constituentis Axiomatibus.” Rees translates this passage as “the right and proper or, at any rate, prime time for subtlety comes when we evaluate experience and build axioms on it”; *Novum Organum*, aph. 121, book I. *Oxford Francis Bacon*, 11: 182-83. In Spedding, the same passage is rendered as “the true and proper or at any rate the chief time for subtlety is in weighing experience and in founding axioms thereon”; *Works*, 4: 108.
22) Bacon employs this metaphor in other parts of his work, and I will discuss it more extensively in a later section of this paper.
ment of the powers and actions of bodies.” As powers and actions are

Circumscribed and measured either by point in space, moment of time, concentration of quantity, or ascendency of virtue ... unless these four have been well and carefully weighed up [fuerint probe & diligenter pensitata], the sciences will perhaps be pretty as speculation [speculatione ... pulchræ], but fall flat in practice [opere inactive].

As in the discussion in Parasceve, Bacon connects proper measurement of physical quantities to efficacy of operations, contrasting such activity with ineffectual speculation.

A final example of the use of the verb “pensitare” belongs to more explicit experimental practice. In Historia densi et rari, the term appears in the investigation of expansion and pneumatic matter, and implies actual measurements of weights.

Now it seemed to me the most certain test [certissima ... probatio] would be that if any tangible body (its bulk having been taken and measured beforehand) could be altogether turned into a pneumatic one, after which the bulk of the pneumatic would likewise be noted down, so that the multiplication of dimension that had taken place could be clearly demonstrated by comparing the values before and after [by weighing both ratios, (pensitatis utriusque rationibus)].

Bacon's description of the experiment is in fact quantitative. A small glass phial is filled with “half an ounce” of spirit of wine, a bladder holding eight wine pints fixed “round the phial’s mouth,” and tightly tied to it. When the phial is placed over hot coals in a brazier, part of the spirit of wine evaporates and inflates the bladder. After removing the phial from the coals and puncturing the bladder, the weight of the evaporated liquid can be evaluated “per lances” (“with the scales”), by weighing the spirit still in the phial.

Now by weight the loss amounted to not more than six pennyweights, so that the six pennyweights spirit of wine, which in a body did not (as I recall) fill a fortieth of a pint, filled a space amounting to eight pints when turned into breath.25

Experientia pensitata, the weighing of experience, is then the driving metaphor of Bacon’s efforts towards the achievement of quantitative histories and experientia literata. It is in the Historia densi et rari that the metaphorical and literal connotations of the expressions are more strongly connected and revealed.

4. Weighing Dense and Rare: from Vulcan to Minerva

The investigation of dense and rare was Bacon’s first subject of choice for the development of an original natural history.26 The initial result of this enquiry was the Phænomena universi, composed in the period of 1610-1611. The Phænomena universi expanded subsequently into the Historia densi et rari. Bacon never published this text, even though, in the Historia naturalis et experimentalis of 1622, he included it among the titles of the histories he pledged to compose in the next six months as the first examplars of a full project of histories—“one … for each month that the goodness of God … prolongs my life.”27

These texts are the best testimonies of Francis Bacon’s extensive efforts to develop a research program of quantitative experientia literata. In the preface to the Phænomena universi, Bacon states that with the development of his history, he aims to leave the “hobgoblins of belief and blindness of experiments” behind and to enter into “a more reliable and sound partnership with things by, as it were, a certain literate experience.” Mechanical arts are Bacon’s major inspiration, because in their operations “judgment is concentrated, and we see nature’s modes and processes, not just its effects”: artificial processes allow the investigator to unveil the usually hidden natural activities. Bacon’s experiments on this subject are quantitative, because “there is no doubt in my mind

25) Ibid., 66-69. For other Baconian versions of this experiment, see Oxford Francis Bacon, 13: 277, note B6′-B7′.
26) On the reasons of this choice, see Rees’ introduction to the Phænomena universi, in Oxford Francis Bacon, 6: xxv-xxvi.
27) Historia naturalis et experimentalis, in Oxford Francis Bacon, 12: 4-7.
that this business” of dense and rare “is capable of being reduced to
calculation [calculos pati possit], to indefinite proportions perhaps in
some things, but to precise and certain ones in others, and known to
nature.”28

In the Historia densi et rari, the metaphor of the weighing of experi-
ence concretely turns into the actual experimental activity of weighing
substances, through which the “business” of dense and rare is reduced
to numbers and measurements. I have already described Bacon’s exper-
imentations on the expansion of pneumatic matter. The trial on pneu-
matic matter is in fact the last of a series of four quantitative experiments.
The report of the first one, which opens the Historia, is introduced by
a long table, with measurements of weights for equal volumes of dif-
ferent substances. The measures and a dry description of “the way in
which the experiment used for the above Table was conducted” com-
plete this first “History.” The second “History” includes two short
tables, with measurements of two types: the first regards “the Bulk of
Matter in the same space or Dimension, in the same Bodies whole and
finely divided”; and the second one is “A Table of the Bulk of Matter
in the same space or Dimension, in Bodies crude and distilled.”

This series of experiments is introduced without specific justifications
regarding their more general goal and purpose. It is only in a subsequent
section, called “Direction” (“Mandatum”), that the aims of and links
between the experiments are clarified:

The two tables above are pretty meagre. The only precise table of bodies and their
openings would be one which displayed the weight of the individual bodies whole
first, then of their crude powders, next of their ashes, limes and rusts; next of their
amalgamations, then of their vitrifications (in those bodies capable of vitriifica-
tion), then of their distillations (once the weight of the water they are dissolved
in was taken away), and of all other alterations of the same bodies; so that in this
manner a judgment might be formed of the openings of bodies and very close-
knit connections on the nature in its whole state29

As Graham Rees has noticed, “Bacon here proposes a further and very
extensive programme of quantitative investigation.”30

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28) Phenomena universi, in Oxford Francis Bacon, 6: 3-11.
describes the goal of his measurements as a general, quantitative exploration of the different states of aggregation of matter. Only through this investigation, which is of course happening at the macroscopic level, by means of measurements and weighing, it is possible to give provisional assessments and judgments regarding the “close-kit connections,” and the actual microscopic structure of substances. This overall goal is further clarified in Novum Organum, where the discussion of dense and rare is developed in the context of Summonsing Instances, or Evoking Instances, which “reduce [deducunt] the imperceptible to the perceptible.”31 As a matter of fact, Bacon also directly uses the expression “Reductive Instances” [Instantias Deductorias], with the same meaning. In this discussion, it is very clear that the quantitative investigation on the “expansion and coition of matter in bodies” is in fact a way to “reduce” the “the most radical and primary difference of schematisms,” which per se would be “imperceptible and intangible.”32

As Bacon explains, “the concentration of matter and its proportions are made perceptible by weight” [deducuntur ad Sensibile per Pondus].”33

Weighing matter is then a way to obtain indirect evidence on its schematisms and microscopic properties. This form of indirect investigation is very significant, and it can be used as an example of Bacon’s idea of what experientia literata can achieve in practice. It is worth remembering that for Bacon the “Application of Experiment,” one of the “modi experimentandi” or operative types of experientia literata, was exemplified by another case of skillful and indirect quantitative investigation by means of weighing, that of Archimedes:

Application of Experiment is nothing but the ingenious translation of it to some other useful experiment. For instance; all bodies have their own dimensions and gravities; gold has more weight, but less dimension than silver; water than wine. From this is derived a useful experiment; for by taking the bulk and the weight you may know how much silver has been mixed with gold, or how much water with wine; which was the eureka of Archimedes 34

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32) Ibid., 351.
33) Ibid., 353.
34) *De Augmentis*, in *Works*, 4: 419 (transl.).
Archimedes’ sagacious type of *experientia literata* is mentioned in the *Historia densi et rari*, too, this time among the “Incentives to Practice”:

1. All mixture of bodies can be laid bare and discovered by means of the table of weights. For if you want to know how much water is mixed with the wine, or lead with the gold, and so on for the rest, then, once you have weighed the composite body, look up the table for the weights of the simple bodies, and the average values of the composite compared with the simple bodies will give you the proportions of the mixture. I imagine that this is Archimedes’ *eureka*, but in any event this is how the matter stands.

Bacon’s indirect investigation follows the same methodological path, as it is possible to transfer and translate the experiments and measurements on the specific gravities of bodies to a much more complex question and experiment, regarding the investigation of the inner and hidden schematisms of matter. As such, it is a concrete example of Baconian *experientia literata*, a sagacious adaptation of an experimental technique to obtain clues and hints on the real target of the Baconian hunt, the hidden properties of matter.

At the same time, like its Archimedean counterpart, the weighing of dense and rare also represents a stage of a metaphorical assay of nature, in which the characteristics of bodies are investigated without the destructive use of fire, but only through reason and sagacity. This idea was very important for Bacon, who actually thought of his new Induction as a form of rational assay. For instance, in the *Novum Organum*, Bacon affirms that

> We must make a separation and dissolution of bodies not by fire indeed but by reason and true Induction with experiments to reinforce them; and by comparing them with other bodies, and reducing them to simple natures and their forms, which in a compound body come together and become intertwined.

Separation “not by fire … but by reason and true Induction” is then the move “from Vulcan to Minerva,” from true fire to the mind, which is a “kind of divine fire.” Also, as I mentioned before, aphorism 20 of Book II further elaborates the metaphor. The Interpretation of

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37) Ibid., 255.
Nature is there represented as a form of assay, based on the careful, quantitative weighing of the instances and tables produced through the histories, the result of which is the First Vintage, and the discovery of axioms.38

5. On Bacon’s Method for the Determination of Specific Gravities

If Archimedean suggestions inform Bacon’s indirect investigations on the quantity of matter in substances, it is also important to establish that his experimental methods strongly differed from those employed by early modern authors belonging to the mathematical Archimedean tradition. As a matter of fact, for the Victorian editors of his works, Bacon’s attempt to measure specific gravities without making use of hydrostatic principles was very puzzling. In his introduction to the Historia densi et rari, Robert Leslie Ellis, comparing Bacon’s method of weighing to those employed by Giambattista della Porta and Marino Ghetaldi, defined it as “the most unmanageable of all.” In fact, he qualified Bacon’s technique as highly unskillful: “nothing can be more inartificial than the process employed.” Bacon formed a hollow prism, of which the height is a little greater than the side and the base—the base being a square, and just equal to a side of a cube of gold weighing one ounce. Any substance to be compared with gold is to be formed into a cube of dimensions equal to the ounce cube of gold, which is ascertained by its just fitting into the prism: the weight of the prism being known both when it is empty, and when it carries a cube of the given substance, that of the latter is also known, and its gravity compared to that of gold is thence determined.

This method, Ellis concluded, “requires it to be possible to give a cubical form to the substance to be examined; a condition in many cases wholly impracticable, and which in all cases will give rise to many sources of error.”39 Most of all, Ellis suggested that Bacon was unaware of the hydrostatic method, of the real “problem proposed to Archimedes,” and “of the idea that specific weights were to be compared by weighing in air and water.”40

38) Novum Organum, in Works, 1: 252 (Spedding’s translation).
40) Ibid., 232-33.
Whereas Ellis’s concerns are historiographically dated, the question of the possible traditions out of which Bacon’s experimental strategies sprang is instead very significant. A first and obvious observation is that Bacon’s experimental research project, in the *Phænomena* and the *Historia densi et rari*, seems to follow quantitative methodologies employed by goldsmiths.

This is explicitly the case regarding units of measurement. While describing his first experiment on “Tangible Bodies,” Bacon clarifies “that the weights I have used belong to the system employed by the goldsmiths, so that a pound has 12 ounces, an ounce 20 pennyweights, and a pennyweight 24 grains,”41 these being the Troy weights employed to weigh precious metals. Bacon uses an ounce of gold as his standard, and determines the weight of an equivalent volume of a substance. All materials are placed in identical vessels, and then weighed.

So I carried out the trial in exactly this manner: one of the vessels was placed empty with the ounce of gold in one scale, the other vessel with the body in it in the other scale, and the difference of weight of the body was taken down.

The weight of a substance is then compared to gold, in order to determine the proportion of matter. For instance, in the particular case of myrrh, “since the gold cube weighs one ounce and the cube of myrrh one pennyweight, it is evident that the bulk of the myrrh compared with the bulk of the body of gold is as twenty to one.” In general, it is worth remembering that one pennyweight corresponds to 1.56 grams, and that Bacon took measures with sensitivities up to the grain, that is to say twenty-four parts of a pennyweight, or 65 milligrams. It is then clear that Bacon was using scales with very good sensitivity, like those used by goldsmiths for coin weighing.42

Because of these considerations, it is reasonable to assume that Bacon’s experimental techniques were modeled on those of goldsmiths weighing coins or precious substances. Still, it would be helpful to find examples of techniques for the measurement of specific weights close

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41 *Historia densi et rari*, in *Oxford Francis Bacon*, 13: 45.
As a matter of fact, it is possible to find at least one example of such a type. This case, which I will discuss in the next section, regards a group of measurements of the specific gravity of metals initially conducted by the French alchemist and experimenter François de Foix de Candale (likely sometime in the decade between 1568 and 1578), and publicized by the polymath and political theorist Jean Bodin in a series of works and texts on political and monetary matters, in the second half of the sixteenth century. The results of these measurements were partially published again in England in 1603, in a work by the merchant and author Gerard Malynes. It is evident that Bacon was familiar with both Bodin and Malynes; he could therefore easily have drawn inspiration from the experiments they reported, rather than relying on the hydrostatic tradition that Ellis and Spedding referred to. In any case, these works demonstrate that it is possible to identify interesting and important examples of use of specific gravity not in a natural philosophical context, but in relation to economy and to monetary matters.

6. Specific Gravities: the Monetary Context and the Issue of Coin Counterfeiting

It useful to start this brief digression considering Jean Bodin’s *Universae naturae theatrum* (1596). Ann Blair has reminded us that in this work, Bodin rarely reported quantitative facts, usually collecting “qualitative and descriptive” information. However,

In only one instance does Bodin engage in a more systematic kind of investigation and in one that involves measurement: he gives a list of the proportions between the weights of different metals and then of a number of other substances, from earth to oil and wine and water, “from which,” he concludes, “can easily be judged the intermediate weights of all natural things.”

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43 For the Archimedean tradition of authors working on specific gravity, see for instance Domenico Bertoloni Meli, *Thinking with Objects: The Transformation of Mechanics in the Seventeenth Century* (Baltimore, 2006), 44-45.

As Ann Blair states, the alchemist Foix de Candale was Bodin’s source. After reporting his results, Bodin affirmed that

This was first demonstrated by François de Foix de Candale, the Archimedes of France, who, taking equal lengths of the six metals drawn into a wire ... weighed them in a very fine balance, and since mercury could not be made into a wire, he impressed a lump [frustulum] of gold or silver on the bone of a squid, then removing the gold piece [auro detracto], poured an equal amount of mercury in it, which he then poured into one side of the balance to find its weight.45

Bodin then adds that “we ourselves collected the weight of salt, earth, salt water, fresh water, wine, ash, and oil, which have not been included in the books of any other writer until now.” Bodin does not explain the techniques he employed to derive this second group of measurements, but it makes sense to imagine that he followed a method similar to that employed by Foix de Candale for mercury. In a different page, Bodin lists weights and proportions found by Foix de Candale, and also gives the results of his own measurements. According to Blair, Foix de Candale’s and Bodin’s accounts on specific weights had a rather limited circulation in French natural philosophical circles:

Excerpted from the rest of the [Theatrum], this passage became one of the sources used in the tables of specific weights compiled and circulated in the early seventeenth century, notably through Mersenne. The authors of these tables, like the fortifications engineer Pierre Petit and the royal physician Louis Savot, cited Bodin alongside Tartaglia, Candala, and others as their predecessors in this research. It is perhaps through this circulation rather than from a direct reading of the Theatrum that Kepler became aware of the passage, the results of which he criticized cogently.46

45) The words in italics indicate my changes to Blair’s translation, which makes use of the term “coin” in both instances: Blair, Theater of Nature, 101. Bodin, Theatrum, 261.
46) Blair, Theater of Nature, 194. On Foix de Candale’s experiments on specific gravities, see also Jeanne E. Harrie, François de Foix de Candale and the Hermetic Tradition in Sixteenth Century France, PhD thesis (University of California, Riverside, 1975), 180-82. Other research on Foix de Candale focuses more strictly on his role as Hermetic philosopher; see for instance Frances Yates, Giordano Bruno and the Hermetic tradition (London, 1964), 173, 179, 182; and Claudio Moreschini, “François Foix-Candale’s Commentary to the Corpus Hermeticum: Historical and Philological Annotations - II
However, it is very interesting to note that Jean Bodin publicized Foix de Candale’s results on the specific gravities of metals in a very different context: in fact, Foix de Candale’s measurements appear in Bodin’s works on politics, economics, and monetary matters. The works reporting these data antedate the *Theatrum*, and are linked to a very popular controversy of that time, the so called Bodin-Malestroit debate on the causes of price increases in France in the 1560s. The texts I am referring to are the third chapter of the sixth book of *Les six livres de la République* of 1576 (which had an English translation in 1606, the *Six Bookes of a Commonweale*); and the second edition of *La response … aux paradoxes de Monsieur de Malestroit*, published in 1578, which in fact included the chapter from the *Six livres* as an addition to a first edition of 1568. Furthermore, Bodin’s and Foix de Candale’s results were partially reported, without acknowledgment, by Gerard Malynes, in his *England’s View, in the Unmasking of Two Paradoxes*, published in 1603.47

A detailed analysis of Bodin’s intentions in these texts is beyond the scope of this article, but it is worth mentioning that a central subject of these works is the issue of ‘false money’. As a matter of fact, a modern commentator, Jérôme Blanc, in contrast to scholars who saw Bodin’s work on this subject as the origin of the ‘quantity theory of money’,48 has proposes to identify it as the fundamental issue behind these texts:

In fact, the central issue Bodin emphasizes is far less the abundance of gold and silver than what we call here ‘false money’. False money was commonly rejected at Bodin’s time. Lacking definition, it concealed monetary manipulations by the Prince behind the rejection of counterfeit coins and coins of bad quality. Clarifying the ‘false money’ accusation allows one to understand the very core of Bodin’s monetary thought: he aimed at building a sound and stable monetary system, that is, a system excluding all sort of false money.49


48) The idea that the amount of money actually circulating in a state affects the level of prices, and in particular, an abundance of gold and silver produces an increase in prices.

49) Jérôme Blanc, “Beyond the Quantity Theory. A Reappraisal of Jean Bodin’s Mon-
It makes sense then that Bodin’s use of specific gravities in these texts is strongly related to the questions of counterfeiting and debasement of money. In the second edition of *La réponse*, following an argument already developed two years before in his *Six livres*, Bodin proposes to stop the stamping of thin coins with a hammer, because the many abuses of this practice. Instead, according to Bodin, “it would be a good idea to have all coins cast in the form of a medallion,” as was common in ancient times: “the mould makes all medallions of the same metal equal in size, weight, breadth and form.” This would make life difficult for counterfeiters:

If a counterfeiter wanted to mix copper with gold more than the alloy of twenty-three carats, the volume of copper being, in equal weight, two and an eighth times bigger than gold, or two and an eighth times lighter than gold of an equal mass, the medallion would be much larger and would thus make the falsification apparent.

In this context, Bodin develops a section wherein he reports the measures on the specific gravities of metals that will reappear in the *Theatrum* of 1596, “as I have learned from François de Foix, the great Archimedes of our time, who first established the true proportions of the metals in weight and volume.” In *La réponse* and the *Six livres* Bodin mistakenly exchanges the figures for lead and silver; moreover, the numerical values for the weights are often wrongly copied from one version of the text to another (including the English translation of *Six livres*); however, taking into account that the weights of silver and lead are clearly exchanged by mistake, these are the measures of Foix de Candale, as reported in the initial work, the *Six livres de la République* of 1576:
From these values, Bodin extrapolates numerical proportions for the ratios between the various metals, which are faithfully reported from one version of this passage to another:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>1550</td>
</tr>
<tr>
<td>Quicksilver</td>
<td>1158</td>
</tr>
<tr>
<td>Lead</td>
<td>998</td>
</tr>
<tr>
<td>Silver</td>
<td>929</td>
</tr>
<tr>
<td>Copper</td>
<td>729</td>
</tr>
<tr>
<td>Iron</td>
<td>634</td>
</tr>
<tr>
<td>Tin</td>
<td>600</td>
</tr>
</tbody>
</table>

(Weights expressed in *Ferlins*)

Such proportions are actually good approximations of the previous numerical values only in the case of the gold/copper, lead/silver, and gold/quicksilver ratios, while they differ more or less significantly in the other cases. It is interesting to note that in 1603 Gerard Malynes reproduced almost verbatim Bodin’s argument on the usefulness of specific weights in the fight against counterfeiting, and copied the pro-

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Approximation</th>
</tr>
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<tbody>
<tr>
<td>gold/copper</td>
<td>17/8</td>
</tr>
<tr>
<td>gold/silver</td>
<td>9/5</td>
</tr>
<tr>
<td>copper/silver</td>
<td>11/13</td>
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<tr>
<td>lead/silver</td>
<td>15/14</td>
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<tr>
<td>tin/silver</td>
<td>9/13</td>
</tr>
<tr>
<td>silver/iron</td>
<td>4/3</td>
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<tr>
<td>gold/quicksilver</td>
<td>4/3</td>
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</tbody>
</table>
portions appearing in Bodin’s works, without reference to Foix de Candale.51

Returning to Bacon, it would seem that the description of Foix de Candale’s experiments in Bodin’s *Theatrum* might for him have been an important source of inspiration, representing a significant case of determination of specific gravities without the use of the hydrostatic principle, but by simple gravimetric techniques. Moreover, Bodin’s use of specific gravities of metals in his discussion of counterfeiting is also suggestive. For Bodin (and Malynes, who appropriated Bodin’s argument) the issue at stake was the precise identification of coins. Univocally establishing the size, weight, and form of coins would eliminate counterfeiting, the accurate measurement of the specific gravities of metals being a guarantee of this fact. In a sense, Bodin applied a case of Archimedean sagacity to a monetary context.

### 7. Quantification and Mathematics in Bacon

My analysis indicates that the weighing of experience was a key aspect of Bacon’s natural and experimental histories. “Weighing of experience” assumed a spectrum of meanings, ranging from the metaphorical to the literal. The latter included quantification of experiments, an integral part of *experientia literata*, the organizing principle of Bacon’s histories. Following the principles of *experientia literata*, Bacon explicitly stressed the necessity of producing—whenever possible—quantitative experiments, providing precise measurements of the properties under consideration. For Bacon, quantification was a necessary component of operative philosophy, that is to say, of his philosophy of experiment. According to Bacon, operation is possible only when “powers and actions of bodies” are precisely known.52 Quantification sets limits to these powers and actions, acting through a sort of transduction, by which the indefiniteness and mutability of nature is reduced and defined in a measurable way. For Bacon this is also the way in which mechanical arts operate. Mechanical arts are eminently quantitative, because in their processes nature is confined and limited. Bacon’s investigation of

52) See section 3.
dense and rare and the wide range of measurements and experiments on the density of matter were the perfect example of quantitative *experientia literata*.

The quantitative features of Bacon’s *experientia literata* have seldom been emphasized by scholars. In a perceptive analysis of Bacon’s reform of natural history, Paula Findlen has delineated well the contrast between the Baconian program and traditional examples of histories. Findlen characterizes Bacon’s rejection of past histories as part of a broader dislike of “triviality,” ornament, and a “frivolous taste for nature.” For instance,

> The humanist embellishments that expanded the scope of natural history in the late sixteenth and early seventeenth centuries certainly heightened the literary qualities of Pliny’s discipline; they were central to the work of such well-known naturalists as Gesner, Aldrovandi and their English imitators. Natural history had become an elaborate enterprise whose popularity derived not so much from its subject as its manner of presentation; in the process nature had been *denatured.*53

For Bacon, natural history was not a matter of delight and entertainment, but of concrete application and operation: natural history was “not meant to be pleasant.”54 Efficacy, as Brian Ogilvie has reminded us, also implied “succinctness and order,” and a rejection of philological concerns.55 Nevertheless, the true point of departure of Baconian histories from traditional examples was still a different one: their experimental, evaluative and quantitative character.

In many ways, an appreciation of these characteristics of the Baconian enterprise still remains confined to Bacon’s scholars. Graham Rees, more than any other author, has in the past decades stressed the innovatory character of Bacon’s quantitative experimental program:

> […] There can be no doubt that he regarded the collecting of quantified data as essential to the successful accomplishment of his programme. He complained that in natural history nothing had been “duly investigated, nothing verified, nothing

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counted, weighed or measured.” In the *Novum Organum* he stressed the absolute necessity of using measuring instruments to the full in order to overcome the deficiencies of the senses […] It is perfectly plain that in principle Bacon believed that quantified data should form a major part of the new natural history—not least because such data would help to generate a *productive* philosophy.56

After analyzing the quantitative and experimental character of the *History of Life and Death* and the *History of Dense and Rare*, Rees commented that “in the light of this it seems scarcely credible that commentators continue to believe that Bacon was neither an experimentalist nor a man for whom quantitative investigation bulked large.”57

Rees’s article is possibly the only extended analysis of Bacon’s quantitative project. This is unfortunate, because the ramifications of Bacon’s program of natural and experimental history extend throughout seventeenth-century natural philosophy and beyond, and not only in a British context. For instance, Peter Dear, in his important reflection on the “meanings of experience” in the seventeenth century, did not consider the very specific, quantitative character of the Baconian program.58 This exclusion is quite problematic. Dear assumed that “the emergence of something resembling ‘experimental science’ in this period occurred most evidently in the so-called mathematical sciences.” According to Dear,

> [f]ollowing the widely accepted Aristotelian view, these were frequently represented as branches of natural knowledge that concerned only the quantitative, measurable properties of things rather than questions having to do with what *kinds* of things they were […] Thus, such sciences as astronomy … and geometrical optics … were branches of “mathematics.” They were also the sciences that made the greatest use of specialized instruments such as quadrants and astrolabes, and sometimes, especially in optics, custom-made experimental apparatus, to generate precise empirical results.59

57) Ibid., 46.
59) Ibid., 119.
However, experiments dealing with quantitative and measurable properties while making use of a custom-made apparatus are exactly what Bacon was developing in his own investigation into the dense and the rare, starting sometime around 1610, the date of composition of the *Phaenomena Universi*. Moreover, as Graham Rees has convincingly showed, Bacon certainly looked very favorably upon the use of specialized instrumentation. The best testimony of this fact is aphorism 39 of Book II of the *Novum Organum*, in which Bacon refers to the useful instances of the Door or Gate, that is, to instruments able to improve or rectify the senses like microscopes, telescopes, measuring rods, and astrolabes.

A further issue with Dear’s discussions is his assumption regarding the origins of what he aptly calls *event experiments*. With this expression, Dear refers to experimental reports of specific tests, which are accounted for in a historical form. Dear suggests that event experiments emerged only late in the seventeenth century, particularly within the Royal Society, and through a process of adaptation of experimental modes derived from the Jesuits and scholastic traditions. This reconstruction obviously eliminates a possible contribution by the Baconian tradition. For Dear, Bacon’s notion of “experience” consisted in the “scrupulous examination and collection of facts regarding the properties and behaviors of physical phenomena.” However, this definition obscures the experimental component of Bacon’s “experience.” Yet, as has been shown above, for Bacon, experience is worthy of interest only when duly weighed through the various procedures defined by the notion of *experientia literata*. But, for Bacon, the weighing of experience is a short way to indicate experimental processes and measurement of properties. Nevertheless, for Dear

[Baconian] facts remained however generic. They concerned “how things behave” and took for granted the establishment of such general facts from singular instances, much like the Aristotelian kind. The main exception was Bacon’s concern with “monsters” and other pretergenerations, that is, individual cases where nature does not behave in its normal, regular way.60

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60) Ibid., 111.
As one of his footnotes makes clear, Dear here refers to the sort of facts appearing in the discussion of the form of heat in the *Novum Organum*, and in particular to the instances in which the nature of heat is present, from aphorism 11 of Book II. However, this table, together with the discussion of the form of heat in the *Novum Organum*, is only a preliminary example and a provisional demonstration of Bacon's method, and should certainly not be taken as an exhaustive example of Bacon’s experimental histories proper. Moreover, in proper experimental histories, the tables are only the final results of an experimental process that is not described in the *Novum Organum*. Instead, Bacon’s systematic construction of the concept of experimental history works exactly in the direction of the establishment of a notion of event experiment, well ahead of the time in which Dear believes this type of experiment originated. Bacon’s accounts of his trials with substances and gases, obviously rhetorically constructed to represent event experiments, clearly have a lot in common with the accounts to which Dear refers.

Very briefly, let us consider the example that Dear uses to introduce the notion of event experiment in his *Discipline and Experience*, namely Newton’s report of an experiment making use of a pendulum:

I suspended a round deal box by a thread 11 feet long, on a steel hook, by means of a ring of the same metal, so as to make a pendulum of the aforesaid length. The hook had a sharp hollow edge on its upper part, so that the upper arc of the ring pressing on the edge might move the more freely … I accurately noted the place … I marked three other places … All things happened as is above described.

Compare this description with Francis Bacon’s account of his trial on the expansion of substances in the *Historia densi et rari*:

I took therefore a small glass phial, which would hold about an ounce. Into this phial I poured half an ounce of spirit of wine … I then took a very large bladder, which would hold eight pints (or a gallon as call it in English) … Out of this I

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61) Bacon calls this provisional attempt as “the first vintage.”
forced all the air ... I then smeared it outside with a little oil, and rubbed it gently, that the porosity of the bladder might be closed up by the oil …63

These accounts are clearly very similar in style, and the exclusion of a role for the Baconian tradition of *experientia literata* in the construction of this type of reports is therefore problematic. In sum, then, it is possible to say that the underestimation of Bacon’s program of quantitative experimentation is part of a more general interpretation of the role of mathematics in Bacon and the Baconian tradition.

This interpretation has been well described by Mary Domski in a recent article on the links between Francis Bacon and the mathematical tradition in the seventeenth century.64 Domski builds on an early, seminal article by Thomas Kuhn, who famously identified two separate traditions to have stood at the cradle of modern science.65 Kuhn’s thesis was particularly innovative because it moved away from the accepted line of explanation, which substantially viewed modern science as an evolution of the methods of what Kuhn called the classical physical sciences of astronomy, statics, and geometric optics. In opposition to these mathematical sciences, Kuhn identified a second cluster of disciplines, which he labeled “Baconian sciences”:

[...]

If Baconianism contributed little to the development of the classical sciences, it did give rise to a large number of scientific fields, often with their roots in prior crafts. The study of magnetism, which derived its early data from prior experience with the mariner’s compass, is a case in point. Electricity was spawned by efforts to find the relation of the magnet’s attraction for iron to that of rubbed amber for chaff. Both these fields, furthermore, were dependent for their subsequent development upon the elaboration of new, more powerful, and more refined instruments. They are typical new Baconian sciences. Very nearly the same generalization applies to heat. [...]

63) Bacon, *Historia densi et rari*, in *Works* 5:352 (transl.).
66) Ibid., 14-15.
Kuhn’s interpretation established a dichotomy between experimental and mathematical disciplines in the seventeenth century. As Mary Domski has emphasized, this division was based on Kuhn’s view that Bacon completely rejected mathematical astronomy and mixed mathematics. According to Kuhn,

Bacon himself was distrustful, not only of mathematics, but of the entire quasi-deductive structure of classical science. Those critics who ridicule him for failing to recognize the best science of his day have missed the point. He did not reject Copernicanism because he preferred the Ptolemaic system. Rather, he rejected both because he thought that no system so complex, abstract, and mathematical could contribute to either the understanding or the control of nature.67

However, as Domski suggests,

[u]pon closer examination of the system of sciences that Bacon urged natural philosophers to establish, we find that he does not demand that astronomy relinquish its use of mathematics, or more generally, that the mixed mathematical sciences relinquish their use of abstraction and idealization. Rather, what he demands is that the mathematical treatment of nature, and of heavens in particular, be grounded on and informed by the findings of natural history.68

In general, as Graham Rees has also pointed out, Bacon did not reject the use of mathematics in the so-called mixed sciences. Instead, he was careful in stating its subordinate character with respect to experiments and natural histories:

Bacon’s point is that we must be careful to put mathematics in its proper place, as a tool that can be used to investigate certain domains of nature after a proper natural history and physics has been established. In other words, we should not begin our study of bodies with the idealization and abstraction characteristic of mathematics; we should only turn to it once a solid foundation of knowledge concerning bodies is in place.69

This shift of interpretation substantially tends to integrate the mixed mathematical program into the Baconian tradition. In particular, Graham Rees suggested that in 1623, at the time of the publication of *De Augmentis*, “Bacon became a stronger advocate of mixed mathematics,” and implied that mathematics had to be considered “auxiliary to all the sciences.” As Bacon put it,

> I have thought it better to designate Mathematics, seeing that they are of so much importance both in Physics and Metaphysics and Mechanics and Magic, as appendices and auxiliaries to them all.

According to Domski, there is evidence that a similar stance was adopted by several later authors associated with the Baconian tradition, and Robert Boyle in particular.

If this new analysis is correct, what is the place of the Baconian program of *experientia literata* in this larger history? In my discussion of quantification in *experientia literata*, I have tried to document how the “weighing of experience” was mostly connected to the efficacy of operations. Bacon, clearly inspired by the example of the mechanical arts, assumed that concrete and practical results can only be achieved when a quantitative experimental program is established. However, in light of these considerations, the requirement for quantification assumes a different sense. As his discussion of mathematics suggests, Francis Bacon seemed to envisage a very general—if auxiliary—role for this discipline. In this way, mathematics was a tool that could be generally applied once natural histories had been properly compiled.

It is then possible that Bacon’s program of data quantification for natural histories was also preliminary to the use of mathematics as envisaged in *De Augmentis*. In fact, mathematics can fully operate only on experimental results that are suitably organized in quantitative form: in this case, quantification of data is a precondition not just for operation, but for the possible employment of mathematics—and these two

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73) See above, sections 2 and 3.
aims possibly overlap, or are indeed identical. Bacon never fully elaborated these points, and in any case it seems that this reassessment of the role of mathematics can be considered an view to which he came late in his work. However that be, this reconsideration of the role of quantification and of mathematics in Francis Bacon seriously calls into question the strong Kuhnian dichotomy between a mathematical and an experimental tradition in seventeenth-century science.\textsuperscript{74}

\textsuperscript{74} Peter Dear reaches similar conclusions describing a largely non-Baconian history of “Physico-Mathematics”; see Peter Dear, \textit{Discipline and Experience}, 246.