

Learning from experiment: classification, concept formation and modeling in Francis Bacon's experimental philosophy

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Abstract:

This paper investigates some examples of Baconian experimentation, coming from Bacon's 'scientific' works, i.e. his Latin natural histories and the posthumous *Sylva Sylvarum*. I show that these experiments fulfill a variety of epistemic functions. They have a classificatory function, being explicitly used to delimitate and define new fields of investigation. They also play an important role in concept formation. Some of the examples discussed in this paper show how Francis Bacon developed instruments and technologies for the production of new phenomena, using them subsequently to define new concepts. In some other cases, experiments can also play an important role in modeling natural phenomena. In examining the role and functions of Baconian experimentation, this paper uses common topics in philosophy of the scientific experiment. With this, it attempts to bridge the gap between the more historical Baconian studies and the contemporary philosophy of science. My examples are chosen with two purposes. On the one hand I intend to show that Bacon was fully aware of the diversity of epistemic functions experiments can play in the process of discovery. On the other hand, these examples are also chosen with the purpose of illustrating a somewhat more general claim, namely that a thorough investigation of Bacon's natural and experimental histories can unveil a more complex picture of the relations between theory and experiment than it has been usually assumed.

Key words: Francis Bacon, experiment, *experientia literata*, modes of experimenting, instruments, models

Introduction

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Francis Bacon has often been called a “philosopher of experiment”¹ and the father of experimental science,² however, his philosophy of experiment has always been subject of fierce debates.³ He was both criticized for paying too much attention to observation and experiment, and for failing to see the role of hypotheses in science,⁴ and for not being experimental enough, for dealing almost exclusively with a non-distinct mixture of

¹ Ian Hacking, *Representing and Intervening. Introductory Topics in Philosophy of Science*, Cambridge: Cambridge University Press, 1983, 246-247.

² This was the first reception and reputation of Francis Bacon in the seventeenth and eighteenth century. He was almost unanimously praised for having ‘disciplined’ experience and for having set the ‘plan’ and ‘model’ of a scientific society. His scientific reputation remained high in the eighteenth-century. The article on “Baconisme ou philosophie de Bacon” in the *Encyclopedie* (ii. 8-10) stressed that “ personne, avant le chancelier Bacon, n’avoit connu la Philosophie expérimentale; & de toutes les expériences physiques qu’on a faites depuis lui, il n’y en a presque pas une qui ne soit indiquée dans ses ouvrages.” Although fragmentary and selective, the eighteenth century reception of Bacon focused on his ‘experimental works’ and on his projects to ground natural philosophy on a well organized and well founded natural history. See Antonio Perez Ramos, *Francis Bacon’s Idea of Science and the Maker’s Knowledge Tradition*, Oxford: Oxford University Press., 1988, Antonio Perez Ramos, Francis Bacon and the Disputations of the Learned, *British Journal for the Philosophy of Science*, 42, 1991, 577-588, Graham Rees, Reflections on the reputation of Francis Bacon’s philosophy, *Huntington Library Quarterly* 65, 2002, 379-394. At the end of the eighteenth century, Condorcet also credited Bacon for discovering “the true method for studying nature.” See Antonio Perez-Ramos, Francis Bacon and the Disputations of the Learned, *British Journal for the Philosophy of Science*, 42, 1991, 577-588 p. 210. In nineteenth century, this way of reading Francis Bacon changed, shifting towards his epistemology and his alleged plans for an ‘inductive science.’ John Herschel and William Wheewel (and to some extent John Stuart Mill as well) have transformed Bacon into the forefather of modern inductive science. See Antonio Perez Ramos, *Francis Bacon’s Idea of Science and the Maker’s Knowledge Tradition*, 20-27, Richard Yeo, An Idol of the Market-Place: Baconianism in 19th century Britain, *History of Science* 23 (1985) 251-98.

³ For a discussion of the conflicting views on Francis Bacon’s philosophy of experiment in the twentieth century see Perez Ramos, *Francis Bacon’s Idea of Science and the Maker’s Knowledge Tradition*, 28-31, 270-285, Paolo Rossi, Ants, Spiders, Epistemologists, in M. Fattori, *Francis Bacon: Terminologia e fortuna*, Rome: Edizioni del Ateneo, 1984, 245-260. For the view treating Bacon’s experimentalism as a ‘myth’ fabricated by the Early Royal Society see Michel Malherbe, 14. Malherbe, L’induction baconienne : de l’échec métaphysique a l’échec logique, in M. Fattori, *Francis Bacon: Terminologia e fortuna*, Rome: Edizioni del Ateneo, 1984, 179-200.

⁴ This is the classical line of attack launched in the early twentieth century by Karl Popper and continued by Popper’s students. On the side of the historians of science, the received view was shaped in many ways by the seminal article of Thomas Kuhn, Mathematical versus Experimental Traditions in the Development of Physical Sciences, in T. Kuhn, *The Essential Tension: Selected Studies in Scientific Tradition and Change*, Chicago: Chicago University Press, 1977, 31-65. Kuhn introduced the sharp divide between “mathematical sciences” and “Baconian sciences” and characterized the latter as being pre-paradigmatic, exploratory and fact-gathering activities. This label stuck in Baconian studies. So much so that there is a considerable amount of literature treating Bacon’s natural history as a mere repository of facts, the result of a painstaking fact-gathering. See Lorraine Daston, Marvelous Facts and Miraculous Evidence in Early Modern Europe, *Critical Inquiry* 11, 1991, 93-124, Paula Findlen, Francis Bacon and the Reform of Natural History in the Seventeenth Century. In D.R. Kelley, (Ed.), *History and the Disciplines. The Reclassification of Knowledge in Early Modern Europe*, Rochester, 1997, 239-261. For the opposite view on Francis Bacon’s natural philosophy see Peter Urbach, *Francis Bacon’s Philosophy of Science*, La Salle, Illinois: Open Court, 1987 and Antonio Perez-Ramos, *Francis Bacon’s Idea of Science and the Maker’s Knowledge Tradition*. For a quite different view on Francis Bacon’s natural history see the articles in the special issue *Francis Bacon and the Transformation of Early Modern Philosophy* edited by Sorana Corneanu, Guido Giglioni, Dana Jalobeanu, *Early Science and Medicine* 17, 2012.

reports, hearsay, and other empirical materials gathered primarily from secondary sources.⁵ Until very recently, the widespread view that Bacon did not actually perform relevant experiments but was merely a fact-gatherer and collector of curiosities, coupled with the dominant hypothetico-deductive view of science, made Francis Bacon's sophisticated methodology of experimentation literally 'invisible' for many historians and philosophers of science.⁶ Even when some of the historians set out to investigate Bacon's ways of performing experiments, they tended to confine their examples to Bacon's most obviously methodological work, the *Novum Organum*, neglecting his more 'scientific' and experimental works: the Latin natural histories and the posthumous *Sylva Sylvarum*.⁷ As a result, even when recognizing the central role of experimentation in Bacon's writings, researchers did not always agree on the precise role experiments were supposed to play with respect to the more speculative aspects of Baconianism.

Attempts have been made to read Bacon in a purely inductivist manner, claiming that he always begun by gathering observations and experiments, establishing some theory-

⁵ This is also one of the 'received views' and 'idols' of Baconian scholarship. It originates in the nineteenth-century in the criticism of Justus Liebig and it was taken over (albeit in a more nuanced manner) by Bacon's Victorian biographer and editor, James Spedding. Nowadays the discussion is centered on the status of experiments and experimental reports in Francis Bacon's natural histories. See Dana Jalobeanu, *The Philosophy of Francis Bacon's Natural history: A Research Program*, *Studii de stiinta si cultura*, 23, 2010, 18-37, Dana Jalobeanu, *Core experiments, natural histories and the art of experientia literata: the meaning of Baconian experimentation*, *Society and Politics* 10, 2011, 88-104, Dana Jalobeanu, *The Four Idols of Baconian Scholarship*, *Procedia - Social and Behavioral Science* 2013 (forthcoming). For a different view on Baconian experimentalism but a very informed discussion of the reception of Bacon's works in the second part of the seventeenth-century see Guido Giglioni, *How Bacon became Baconian*, in Sophie Roux and Daniel Garber eds. *The Mechanization of Natural Philosophy*. New York: Springer, 2013 (forthcoming).

⁶ For a discussion see Ian Hacking, *Representing and Intervening*, Cambridge: Cambridge University Press, 1983.

⁷ The same happened with the scholars interested in the epistemology of experiment. See Marta Fattori, *Experientia-experimentum: une comparaison entre les corpus latin et anglais*, in Marta Fattori, *Etudes sur Francis Bacon*, Paris, PUF, 169-187 for a view saying that Bacon's natural histories are not relevant for Bacon's epistemology and methodology of experimentation, because they are merely 'examples'. See also Didier Deleule, *Experientia-experimentum ou le mthe du culte de l'experience chez Francis Bacon*, in in M. Fattori, *Francis Bacon: Terminologia e fortuna*, Rome: Edizioni del Ateneo, 1984, 59-72. It is especially highly relevant that one of the most intriguing 'experimental' works of Francis Bacon, the posthumous *Sylva Sylvarum* (1626) considered by many of the seventeenth-century naturalists as no less than a handbook of experiments, experimental ideas and suggestions has been almost neglected by the twentieth century Baconian studies (or by the philosophers of science, for that matter). Even Hacking's attempt to recuperate Bacon's philosophy of experiment is conducted almost solely with examples coming from *Novum organum*. The same is valid for Lisa Jardine's seminal article on Francis Bacon's *experientia literata*. See Lisa Jardine, *Experientia literata or Novum organum: Bacon's two scientific methods?* In W. Sessions, ed., *The Legacy of Francis Bacon*, AMS Press, New York, 1990, p.47-67. For a discussion of the reasons of this curious neglect see Graham Rees, *An Unpublished Manuscript by Francis Bacon: Sylva Sylvarum Drafts and Other Working Notes*, *Annals of Science* 38, 1981, 377-412.

free facts and constructed from them, through some sort of inductive reasoning, axioms and laws.⁸ There were also attempts to read Bacon as a hypothetico-deductivist: as starting with conjectures and theoretical statements and using experiments to test, confirm or reject theoretical statements.⁹ Yet other attempts picture Bacon as a proto-Bayesian: as using experiments to amass evidence for a more probable conjecture and amend his theory accordingly.¹⁰ Other scholars hold that Bacon was first and foremost a speculative philosopher, in the tradition of Renaissance vitalism (best expressed in the work of Bernardino Telesio) and cosmological thinking. As a consequence, these scholars tend to see Bacon's 'experiments' as simply illustrating his appetitive and pneumatic matter theory.¹¹ Last but not least, there are the ways of reading Bacon centered upon his rhetoric: his natural history and discourse about the importance of experiments are seen in this case as purely rhetorical devices for realizing the societal and communitarian program of *Instauratio Magna*.¹²

In this paper I would like to avoid any attempt to present a unified picture of the role and purpose of Baconian experimentation. Instead, I investigate some examples of Baconian experimentation, coming from the Latin natural histories and the posthumous *Sylva Sylvarum*. In doing this, I will have a closer look at the types of questions Bacon developed with the help of some such experiments, emphasizing their diversity and their

⁸ For a thorough critique of this 'Popperian' view of Bacon see Antonio Perez-Ramos, *Francis Bacon's Idea of Science and the Maker's Knowledge Tradition*, 270-285. However, a version of the 'inductivist' Bacon is still held by Lorraine Daston, *Marvelous Facts and Miraculous Evidence in Early Modern Europe*, *Critical Inquiry* 11, 1991, 93-124.

⁹ Peter Urbach, *Francis Bacon's Philosophy of Science*.

¹⁰ L.J. Cohen, *Some historical remarks on Francis Bacon's Conception of Probability*, 41, 1980, 219-231, Silvia Manzo, *Probability, Certainty, and Facts in Francis Bacon's Natural Histories: A Double Attitude against Skepticism*. In Neto, Maia; Raimundo, José; Paganini, Gianni and Laursen, John Christian (eds.), *Skepticism in the Modern Age: Building on the Work of Richard Popkin*. Leiden: Brill, pp. 123-137.

¹¹ This is the direction in which some of the work of Graham Rees is pointing (although he also has more nuanced articles regarding Bacon's experimental works). See Graham Rees, *Matter Theory: A Unifying Factor in Bacon's Natural Philosophy*, *Ambix* 24, 1977, 110-125, Graham Rees, *Bacon's Speculative Philosophy*, in M. Peltonen, ed., *The Cambridge Companion to Bacon*, Cambridge: Cambridge University Press, 1993, 121-145. More straightforwardly belonging to this direction are a couple of seminal papers by Guido Giglioni. See for example, Guido Giglioni, *Mastering the Appetites of Matter: Francis Bacon's Sylva Sylvarum*, in C. T. Wolfe, O. Gal, (Eds.) *The Body as Object and Instrument of Knowledge: Embodied Empiricism in Early Modern Science*, Dordrecht: Springer, 2010, 149-167, Guido Giglioni, *Reading Nature without making a Book of It: Francis Bacon Novum organum*, in P. Hummel, ed., *Mémoires / Misbooks. Études sur l'envers et les travers du livre*, Paris: Philologicum, 2009, 55-70.

¹² This is also a direction of interpretation originating in the nineteenth century criticism of Justus Liebig, which proved to be surprisingly enduring. See Justus Liebig, *Lord Bacon*, translated by P.A. Chickhachev, Paris, 1866 (translation of: *Ueber Francis Bacon von Verulam und die methode der naturforschung*, Muenchen, 1863).

continuous interplay with methodological and technical questions relating to the experimental set-up, instruments and to the variations of the experiment itself. I intend to show that in the examples presented, experiments fulfill a variety of epistemic functions. They have a classificatory function and they are explicitly used to delimitate and define new fields of investigation. In some cases, Bacon developed instruments and technologies for the production of new phenomena and he used them to define new concepts. In some other cases, experiments played the role of artificial models of natural phenomena. I will show that Bacon used strings of experiments, experimental techniques and exploratory experimental strategies in the process of concept formation and modeling. These and similar issues are common topics in the recent philosophy of the scientific experiment.¹³ In the current investigations the history of these topics is often traced back to Francis Bacon,¹⁴ however, such genealogy is rarely more than mere lip-service and name-dropping. With very few exceptions, the new experimentalists were not interested in reading Bacon and even those that did confined their discussions and examples to the list of ‘prerogative instances’ developed by Francis Bacon in *Novum organum*.¹⁵ What I propose in terms of examples are experiments included in Bacon’s natural historical works, often within more elaborated strings of experiments generated with the help of the ‘rules’ and ‘modes’ of *experientia literata*. My examples are chosen with two purposes. On the one hand I intend to show that Bacon was fully aware of the diversity of epistemic functions experiments can play in the process of discovery. On the other hand, these examples are also chosen with the purpose of illustrating a somewhat more general claim, namely that a thorough investigation of Bacon’s natural and experimental histories can unveil a more complex picture of the relations between theory and experiment than it has been usually assumed.

¹³ See for example Friedrich Steinle, Entering New Fields: Exploratory Uses of Experimentation, *Philosophy of Science* 64 (1997) S65-S67, C.Kenneth Waters, The Nature and Context of Exploratory Experimentation: An Introduction to Three Case Studies of Exploratory research, *History and Philosophy of Life Sciences* 29 (2007) 257-84.

¹⁴ See for example Friedrich Steinle, Experiments in History and Philosophy of Science, *Perspectives on Science* 10 (2002), 408-432, Ian Hacking, *Representing and intervening. Introductory topics in Philosophy of Science*, Cambridge, Cambridge University Press, 1983.

¹⁵ Hacking, *Representing and intervening*, Ch. 5.

Additional difficulties: Experimenting with spirits

One of the most problematic aspects of Baconian experimentation comes from the unfamiliar way they are supposed to bridge the gap between the invisible, causal level of the world and the visible, phenomenal level.

For the seventeenth-century mechanical philosopher, the way to bridge the gap between minute invisible particles and their visible effects is by postulating a fundamental similarity between macroscopic/visible phenomena and what happens at the microscopic level. Collisions, for example, are relevant from the point of view of the experimenter because of the postulate stating that in the visible and invisible world, particles or macroscopic bodies collide in the same way, like billiard balls. Hence, it is relevant to study the macroscopic collisions and investigate the empirical laws governing this phenomenon.

In Bacon's non-mechanical and vitalistic philosophy, however, no such postulate of similarity is at work. There is no reason to believe that the invisible spirits trapped in bodies act in any way similar with the macroscopic bodies we can see and experience. As it has been shown time and again, Bacon divides matter into two classes: tangibles and pneumatics, the latter category being referred to with the common name 'spirit'. The spirits are the active, causal 'part' of matter producing all the visible effects physics is supposed to describe and explain. Tangible matter is 'sluggish' and inert and it is a source of action only insofar as it is 'inhabited' by various kinds of spirits. Meanwhile, at the spiritual (pneumatic level), matter is forever in a state of war: spirits are active, animated by appetites, and engaged in a continuous struggle.¹⁶ They fight each other and prey on matter, and their appetites and motions are the ultimate causes of all physical phenomena. What all the following examples have in common is that they are said to be experiments performed with/on this particular form of matter. It is this form of matter which, according to Bacon, is responsible for producing effects in the natural world. Spirits are

¹⁶ On Bacon's appetitive theory of matter see Guido Giglioni, *Mastering the Appetites of Matter: Francis Bacon's Sylva Sylvarum*, Graham Rees, *Francis Bacon's Speculative Philosophy*, Graham Rees, *Atomism and Subtlety in Francis Bacon's Philosophy*, *Annals of Science* 37, 1980, 549-571. See also Sophie Weeks, *Francis Bacon and the Art-Nature Distinction*, *Ambix* 54, 2007, 101-129.

“the most active of bodies” (SS I, 98) and it is from spirits “and their motions” that the majority of processes proceed: “rarefaction, colliquation, concoction, maturation, putrefaction, vivification and most of the effects of nature” (SS I, 98, HVM, OFB XIII 348-9 adding ‘liquefaction’ and ‘arefaction’ to the list). All properties of bodies arise, Bacon claims, from the ‘appetites and desires’ of pneumatic matter.¹⁷ No wonder, therefore, that Bacon claims that every investigator of nature should *begin* with questions such as:

in every body we must investigate how much of it is spirit and how much tangible matter; and whether the spirit itself is plentiful and swelling or scanty and starved; whether thinner or thicker; more airy or fiery; active or idle; robust or insubstantial; advancing or retreating; cut off or continuous, agreeing or disagreeing with external and ambient bodies etc. (NO, OFB XI, 213)¹⁸

How can one operate such an investigation into the relative proportion and interactions between spirits and matter? It is here where the experimenter is called upon to play an important role. His is the task to ‘measure’ the relative quantities of spirits and matter and to find ways to ‘measure’ the actions and effects of all the appetites, desire and motions of spirits. The proper objects of philosophy, the “principles, fountains, causes and forms of motions, that is, the appetites and passions of every kind of matter” (OFB V, 246) are to be investigated throughout an experimental procedure sometimes pictured as chaining Proteus and hence obliging matter to change shape and reveal its secrets.

... we should investigate those appetites and inclinations of things by which all that variety of effects and changes which we see in the works of nature and art is made up and brought about. And we should try to enchain Nature, like Proteus; for the right discovery and distinctions of the kinds of motions are the true bonds

¹⁷ OFB V, 431-2.

¹⁸ See the list of abbreviations at the end of the paper. My quotes from Bacon will follow *The Oxford Francis Bacon* (OFB) unless otherwise stated. The exception is *Sylva Sylvarum* for which we still have to rely on the nineteenth century edition of Spedding, Ellis and Heath, hereafter SEH.

of Proteus. For according as motions, that is, incentives and restraints, can be spurred on or tied up, so follows conversion and transformation of matter itself. (*Cogitationes*, OFB 5, 425)

Experimenting with matter or chaining Proteus means, in fact, experimenting with spirits, reaching, through experiments, to the sources of motion and causation that lies behind all the processes and phenomena.¹⁹ However, this process is fraught with difficulties. First, most spirits are ‘rare’, subtle and invisible: we cannot ‘see’ them. Second, although they are highly active, it is not entirely clear how we can measure this activity, other than through its visible effects in the world of bodies surrounding us. Thirdly, Bacon insists that spirits are different in almost every way from the tangible bodies.

Here, an example might be useful to illustrate some theoretical and practical consequences of Bacon’s views:

Take a glass, and put water into it, and wet your finger, and draw it round about the lip of the glass, pressing it somewhat hard; and after you have drawn it some few times about, it will make the water frisk and sprinkle up in a fine dew. (SS I.9, SEH II 342)

Bacon sees this simple experiment as ‘demonstrating’ the force of compression present in every solid body. It is a visible effect of an appetite of spirits to react to external compression:

For whensoever a solid body... is pressed, there is an inward tumult in the parts thereof, seeking to deliver themselves from the compression... Wherein it is strange in the highest degree, that this motion hath never been observed nor

¹⁹ There are many passages where Bacon emphasizes that the real and relevant questions regarding the nature of matter and its processes relate to the appetites, desires and passions of the spirits enclosed in tangible bodies and not to the tangible bodies per se. For example: *Sylva*, 846, SEH II 618.

inquires; it being of all motions the most common, and the chief root of all mechanical operations. (ibid., SEH II 342)

This motion is one of the fundamental motions of pneumatical matter, the motion of liberty. In this particular experiment, the inquirer of nature is however observing an effect of the motion of liberty in a particular experimental set up where its effects become visible. Although this is a motion present in every body, it is only in liquids that this motion can be made visible; at least this is Bacon's interpretation of the observation that all "liquors stricken make round circles" (SEH II 342). Hence, the explanation of the experiment is the following:

...the pressure of the finger, furthered by wetting (because it sticketh so much the better unto the lip of the glass) after some continuance, putteth all the small parts of glass into work, that they strike the water sharply; from which percussion that sprinkling cometh. (SEH II 342)

In other words, Bacon seeks to explain the visible effect of this simple experiment (tiny droplets of water will sprinkle the glass about the water level in a "fine dew") by appealing to a universal and invisible motion under pressure – or, rather, *reaction* to pressure. He sees this tendency to react to being compressed or constrained in any way as a universal property of matter. In the example above, the pressure of the finger upon the brim of the glass has 'awaken' this reaction in the particles of the glass which in turn are acting against the water and produce the same reaction in the liquid. The tiny droplets of water 'rising' on the glass are a 'measure' of this inner motion present in each body which Bacon calls 'motion of liberty'. It is clear why one can be tempted to say that experiments play for Bacon a simple illustrative role of his speculative matter theory; that they are devices (arguably rhetorical devices) to make visible the (effects of the) processes of nature. In this case, the experiment is making visible the hidden motion of liberty present in liquids. Meanwhile, the above experiment does not stand alone; it is one

in a series of experiments dealing with the motion of liberty.²⁰ If some of them are ‘illustrative,’ some are clearly moving beyond the task of mere ‘illustrating’ effects of the motion of liberty into inquiring how various bodies (and implicitly spirits) behave under pressure. They are asking, for example, what is the precise way in which various kinds of bodies (solid, liquid, gaseous, sounds etc.) attempt to ‘restore’ and ‘release’ themselves from pressure. Is the tendency to move ‘round’ until an escape is found, also present in solids, in mixtures, such as gunpowder, in spiritual or inflamed bodies? The last experiment in the series is extending the ‘results’ obtained in the various ‘illustrations’ of the motion of liberty beyond the mere motions of matter into the production of sounds.

This motion upon pressure is excellently also demonstrated in sounds; as when one chimeth upon a bell, it soundeth; but as soon as he layeth his hand upon it, the sound ceaseth: and so, the sound of a virginal string, as soon as the quill of the jack fallen upon it, stoppeth. For these sounds are produced, by the subtle percussion of the minute parts of the bell, or string, upon the air; all one, as the water is caused to leap by the subtile percussion of the minute parts of the glass, upon the water... For you must not take it to be, the local shaking of the bell, or string, that doth it.

In other words, for Bacon, what produces the sound is ultimately the motion of liberty; on percussion, the inner motion of liberty causes the particles of the bell (or string) to move in a direction contrary to that of percussion and to ‘reach outside,’ acting on the surrounding air. The above experiment shows that this is so *because* if one touches the bell, interposing his hand between the bell (or string) and the outer air, the sound ceases. The same experiment is used to correct what Bacon claims is a “wonderful Errour amongst Men” who take the persistence of every sound (once the percussion has ceased) to mean a “Continuance of the First Sound; whereas (in truth) it is a Renovation, and not a Continuance.” (SS III 207, SEH II 415-6). From the fact that if one touches the bell with the hand, the sound ceased, one has to infer that the persistence of sounds in general

²⁰ Called *Experiments in consort touching the motion of bodies upon their pressure*, SEH II 342-343. On the motion of liberty see *Novum organum* OFB XI 385-387.

is due not to a ‘persistence’ of the effects of percussion, but to a renewed action of the particles of the bell upon the surrounding air.

To sum up, Bacon ascribes to the above experiments a series of epistemic functions: they ‘illustrate’ and ‘demonstrate’ the motion of liberty, but they also inquire into the particular ways in which this universal motion acts (or the effects it has) in solid, liquid, gaseous and flamy bodies (without formulating a common hypotheses as a result of this inquiry). Another function of the experiments discussed above is to contradict common opinions and prejudices regarding the nature and behavior of sounds. Last but not least, they are also employed in the formulation of a generic working definition for the motion of liberty as the ‘attempt’ of every body to react to pressure (including percussion) and ‘tensure’ (SS I 12 SEH II 342-3). Such a diversity of epistemic functions is by no means unusual in Bacon’s natural histories, as I will show in the next sections.

Multiple uses of an instrument and concept formation

In a series of papers I have tried to show that in many cases Bacon devised experiments in an ordered series, through a process very similar to what has been sometimes called “exploratory experimentation”, i.e. through an orderly variation of the experimental parameters.²¹ Sometimes, this process of exploratory experimentation aims simply at understanding more about a novel process or effect observed in nature. Some other times it fulfills more complex epistemic functions, such as classification or, to use Steinle’s phrase, “the formation of classificatory and conceptual frameworks.”²²

Sometimes, what generates the process is an interesting instrument, such as calendar glass, or the weather glass (*vitrum calendare*). Here is how Bacon describes the instrument:

²¹ Jalobeanu, The Philosophy of Francis Bacon’s Natural history, Jalobeanu, Core experiments, natural histories and the art of *experientia literata*. See also Dana Jalobeanu, *The Hunt of Pan: Francis Bacon’s art of experimentation and the foundations of science*, Zeta Books 2013 (forthcoming). For the notion of exploratory experimentation see Steinle, Experiments in history and philosophy of science and Steinle, Entering New Fields: Exploratory Uses of Experimentation.

²² Steinle, Exploratory uses of experimentation, S71.

...take a glass with a concave belly, a thin and elongated neck; turn it upside down and lower it belly up and mouth down into another glass vessel holding water, with the mouth of the inserted glass touching the bottom of the vessel receiving it, and the neck of the first glass leaning a little against the mouth of the second, so that it can stand up – and to achieve this more conveniently, put a little wax on the mouth of the second glass... (OFB XI 249-251)

Next, Bacon explains the functioning of this instrument: the upper glass is heated before being reversed and fixed in the lower glass. When cooling down, it ‘draws’ the water on its long neck. In this inverted glass device, one can see the ascent and descent of the water and one can even attach a measuring scale to the instrument:

Now a long, narrow scale should be attached to the glass and graduated as one chooses. Then, as the day’s weather gets warmer or colder, you will see the air contract into a smaller space with cold and expand into a larger with heat, as can be made out by the water rising when the air contracts and falling or being pushed down when it expands. (OFB XI 251)

One use of such a device is to measure changes taking place in the air. The weather glass, claims Bacon in *Historia densi et rari* “as far as heat and cold are concerned, demonstrates the varieties and degrees of the weather so nicely”(OFB XIII 89). Of all other bodies and most of the spirits “air is the body which takes in and gives off heat most readily” (OFB XI 249):

The air’s sense, as far as hot and cold is concerned, is so much subtle and exquisite that it far surpasses our faculty of touch, so much so that a sun-beam, or the heat of the breath or even more the heat of the hand placed on top of the glass, immediately and manifestly makes the water sink. (OFB XI 251)²³

²³ See also: OBF XIII 89

This weather-glass or calendar glass occurs many times in Bacon's natural and experimental histories and gives rise to a number of different experiments.²⁴ As it is often the case, the weather glass itself is not Bacon's own invention. In fact, at the time it gained such a prominence in Bacon's writings, the calendar glass was already featuring in other natural histories of the period.²⁵ As Arianna Borelli has shown, unlike his predecessors Giovanni Battista della Porta, Giovanni Battista Benedetti and Cornelius Drebbel, Bacon transformed what was a "temporary experimental set-up" into a permanent device/instrument, the *vitrum calendare*.²⁶ He also used this instrument in a variety of ways, going beyond treating it as a simple device to 'measure' the ways in which air receives or gives away heat and cold. And he did this through and exploratory experimentation.²⁷ In a series of experiments, Bacon played with the elements of the weather-glass in order to identify the relevant parameters in such experiments. He begins by placing hot and cold substances and materials on the upper part of the calendar glass (OFB XIII 89, 107, 109, 139). Then, he inquired whether substances that have a cooling effect in living beings (without being cold themselves), such as opiates, for example, are 'felt' by the weather glass (SS I 74 371). In HDR he makes a list of "potential heats" [caloribus potentialibus], i.e. medicines and other substances producing the dilatation of spirits and asks whether one can produce a weather glass sensitive enough to measure them. He proposes the following experiment

²⁴ See for example HV, OFB XII, 71, HDR OFB XIII 89, 107, SS I 74, SEH II 371, SS IX 811, SEH II 605 etc. Weather glass is the term Bacon uses in *Sylva Sylvarum* for the same device called 'vitrum calendare' in *Novum Organum*, *Historia ventorum* and *Historia densi et rari*.

²⁵ Arianna Borelli, *The Weatherglass and its Observers in the Early Seventeenth Century*, in Claus Zittel et al., *Philosophies of Technology. Francis Bacon and his Contemporaries*, Brill, 2008, 67-133.

²⁶ Borelli, *The Weatherglass and its Observers*, 116.

²⁷ We can see Bacon's weather-glass as a device specially set up for exploratory experimentation because it allows all sorts of interventions of the experimenter in its design: the change of water with wine or "spirit of wine," for example, the construction of two identical weather-glasses which can be carried around and their measured results can be compared etc. According to Steinle, a characteristic feature of exploratory experimentation is that it enable investigators to intervene in a variety of ways. See Steinle, *Entering new fields*. For a discussion of other, larger concepts of exploratory experimentation see Ken Waters, *The Nature and Context of Exploratory Experimentation*, p. 2-5. A common definition of exploratory experiments is that they are aiming "to generate significant findings about phenomena without appealing to a theory about these phenomena for the purpose of focusing experimental attention on a limited range of possible findings" (Waters, *ibid.*, 5). For a more general discussion of exploratory experimentation see also L.R. Franklin, *Exploratory Experiments*, *Philosophy of Science* 72, 2005, 888-899.

Take two calendar glasses of the same size. Put water in the one and spirit of wine strong and sharp in the other, and so heat the glasses that the water and spirit climb to the same height. Put them together and leave them for a while and see if the water stands higher than the spirit of wine. For if that is what happens it is obvious that the potential heat of the spirit of wine has dilated the air so as to push down the spirit of wine. (OFB XIII 109).

Moving beyond the mere sensitivity of the air, Bacon uses two equally calibrated weather-glasses to *measure* (or at least to compare) properties and qualities of weather and the disposition of air situated in different places. For this, he uses two ‘identical’ weather-glasses and interprets their different results as a measure of the differences in air between two different places:

Because it is certain that in some places, either by the nature of the earth, or by the situation of woods and hills, the air is more unequal than in others; and inequality of air is ever an enemy to health; it were good to take two weather-glasses, matches in all things, and to set them, for the same hours of one day, in several places, where no shade is, nor inclosures; and to mark where you set them, how far the water cometh; and to compare them, when you come again, how the water standeth then; and if you find them unequal, you may be sure that the place where the water is lowest is in the warmer air, and the other in the colder. And the greater the inequality be of the ascent or descent of the water, the greater is the inequality of the temper of the air. (SS IX 811, SEH II 605).

This experiment uses the weather-glass as a measuring instrument and establishes a long-term research program (repeated measurements at regulated intervals, during summer and winter etc.).²⁸ But there are other exploratory manipulations of the weather glass in

²⁸ See also the testimony of Thomas Bushell and Thomas Tennison about Bacon’s ‘mechanical inventions’ among which there was a “Philosophical Glass” destined to “know the Season of every Hour of the Year”. See *Baconana, or Certaine Genuine Remains of Sir Francis Bacon*, London, 1679, 18-19. It is important to stress that Bacon does not have a theory about what exactly his weather-glasses are measuring; what are the ‘qualities’ and ‘virtues’ of the air. He has something different, very similar with what has been recently labeled “exploratory research program,” namely a series of research strategies and experimental ideas (of

Bacon's writings. One is quantitative: Bacon asks simply how much can the air inside of the weather-glass be rarefied? The regular procedure is to bring water to boil, empty the glass and then turn it upside down in the other vessel with cold water. As a result, the water will raise and occupy 1/3 of the glass. Can we make the water rising further than this? Is it possible to rarefy the air inside of a vessel in such a way that it gets to the same degree of rarefaction as the ether or the celestial fire? If we replace the glass with stronger materials, iron or bronze, 'how far the rarefaction could be taken'? (HDR, OFB XIII, 89). The question is left without an answer in HDR, but the experiment is taken further, into the direction of other questions. An interesting one relates to the possible relations between heat/cold and dense/rare. For example, Bacon asks whether the degree of rarefaction has anything to do with the capacity of retaining heat/cold for a longer period of time. He also imagines an experiment that would eliminate the parameter 'heat' and retain only 'dilatation/condensation':

It would be well worth while showing by experiment whether air dilated by heat could be fixed in that same bulk so that it would not make efforts to restore or contract itself. So take a stout calendar glass and heat it strongly; then stop its mouth up well so that the air cannot contract again, and leave it stopped up for some days. Then put it still stopped up in water, and once it is in the water open it up and see how much water it draws in, and whether it draw in as much as it would have done if the glass had been put in the water straight away. (OFB XIII 139)

This experiment points already in the direction of an entirely different field of experimentation. Under investigation is a new 'power' of the dilated air to draw water. The heated and dilated air has the power to push water down or, when it cools down, it draws water up. Is this power the same if the dilated air is cooled down in a closed recipient? Moreover, this power of drawing water or pushing it down makes the weather-

an exploratory nature) which have to be conducted all together in order to learn more about the 'properties' and 'virtues' of the air. Placing weather-glasses in various locations is just one part of such a larger program. Other elements of it include studying the growth of similar species of plants and vegetables in different locations (for comparative study) and leaving pots of water and pieces of raw meat in the same locations for an equal amount of time to study whether the way they putrefy differ. See SS Century IX.

glass a very useful instrument for studying another class of phenomena, that of winds. The weather glass is therefore used in HV as a device for producing artificial winds: “In a calendar glass dilated air pushes the water down as if it were a breeze” (OFB XII, 71). To say that the air in the weather glass behaves as a breeze means, for Bacon, that one can, in fact, use the weather glass to produce an artificial wind and, by extension, that one can develop devices exploiting the same phenomenon (i.e. the creation of ‘winds’ through dilatation and condensation) in order to extend the inquiry into the properties of winds properly speaking. Here is how Bacon recounts the experiment:

I have conducted an experiment on this kind of wind in a round tower closed on all sides. I placed a brazier in the middle of it with coals well alight so that there would be less smoke. But at some distance from a side of the brazier I hung a thread with a cross of feathers to make it move more easily. In a short time then, when the heat had increased and the air dilated, the cross and its thread were stirred back and forth with changeable motion; and when a hole was made in the window of the tower, a hot current of air went out, not steadily but intermittently and with fluctuating intensity. (OFB XII 71)

A number of very interesting facts are reconstructed here: Bacon generates a wind through the same kind of experimental procedure as before: heating up the interior of a sealed vessel and producing the ‘swelling’ of the air. He even keeps the geometry of the weather-glass: a high hollow space on the top, a source of humidity on the ground, and a gradient of temperature.²⁹ Currents of convections are formed, hence the feathers are oscillating. Moreover, when we open the closed vessel/tower, blasts of hot air are getting out.

This “tower experiment” is discussed a couple of times along the HV, with interesting variations of the experimental conditions. Bacon replaces the brazier first with a boiling kettle, so that hot vapors are released in the enclosed tower. What happens is that the feathers are moved “more weakly and lazily”. He then uses both the brazier with burning

²⁹ In the first version of the experiment the humid vapors enclosed in the tower are put into motion by the heat of the brazier. After that, Bacon introduces a separate source of water on the bottom, i.e. a boiling kettle. See OFB XII 71, 83.

coals and the kettle to produce both a current of hot air and a lot of vapors and, of course, the motion of the feathers is more pronounced: “such as that is was sometimes rotated upwards as if by a tiny whirlwind, since the water supplied an abundance of vapor which the brazier was ready to dissipate” (OFB XII 83).

By creating artificial winds through this process of exploratory experimentation (varying the gradient of heat, introducing an additional source of water etc.), Bacon claims to have proven that “the main cause provoking wind motion is the overburdening of the air with added air made of vapour.” (OFB XII, 83) He also claims to have shown that there is no reason to assume that winds are a particular substance or a virtue of air, as the ancients have taught. Instead, one can show, by way of such experiments, that winds are simply motions of pneumatics (air, vapors) originating in waters (rivers, sea, clouds) and moved around according to the varying degree of density of the surrounding air. In this way, the experiment can be said to refute commonly received opinions and the current meteorological theories claiming that a wind is ‘more’ than a mere motion of the air.³⁰ Meanwhile, the experiment establishes a number of interesting provisional connections between varying the density of the air, the presence of water and water vapors and the variation of temperature (to use modern language).

In other words, exploratory experimentation is used to establish the relevant parameters of an artificial model for studying the winds. At the same time it also is used to ‘classify’ various motions of the air produced in the weather-glass and in the tower experiment under the general category ‘winds’. A definition is given to these ‘winds’ in terms of the parameters identified in the experiments, namely ‘winds’ are motions of the air produced by the ‘swelling’ of the atmosphere when vapors of water are added into it. Winds originate in ‘nurseries’ of water: rivers, sea, clouds or mere boiling pots can be such wind-nurseries.

Experiments as models

³⁰ See also Borelli, *The Weather-Glass and its Observers*.

The tower experiment also has a modeling function. In it, we can see, for example, on a smaller scale, what Bacon claims to be the case in nature, namely that adding vapors into the atmosphere and varying the temperature creates a stronger blast of the air than each of the effects separately. By analogy, the presence of a massive quantity of water (such as a river or the sea) is a ‘nursery’ for a larger wind and a variation of temperature on a bigger scale (like the heat of the sun) will produce similar effects.

This modeling aspect is even more striking in another series of experiments Bacon referred to throughout his works, i.e. experiments destined to create a table-top model of a star. The experiment is described thus:

Take a small wax candle, and put it in a socket of brass or iron; then set it upright in a porringer full of spirit of wine heated; then set both the candle and spirit of wine on fire, and you shall see the flame of the candle open itself, and become four or five times bigger than otherwise it would have been; and appear in figure globular, and not in pyramis. You shall see also, that the inward flame of the candle keepeth colour, and doth not wax any whit blue towards the colour of the outward flame of the spirit of wine. (SS I. 31, SEH II 259)

This flame-in-a-flame experiment is also used in an exploratory manner to ask a number of questions about the nature and properties of flame. According to Bacon, this “noble instance” shows at least two different things: that flame is a “fixed body” and not a ‘transitory’ effect, and that its properties are different according to the medium in which it burns. Not only that “flame doth not mingle with flame” (unlike air or water) but also the shape of flame inside of a flame is different from its shape in the air:

It appeareth also that the form of a pyramis in flame, which we usually see, is merely by accident, and that the air about, by quenching the sides of the flame, crusheth it, and extenuatheth it into that form; for of itself it would be round; and therefore smoke is in the figure of a pyramis reversed; for the air quencheth the flame and receiveth the smoke. Note also, that the flame of the candle, within the flame of the spirit of wine, is troubled; and doth not only open and move

upwards, but moveth waving, and to and fro; as if flame of his own nature (if it were not quenched) would roll and turn, as well as move upwards.(SS I. 31 SEH II 352-3).

What we see again in this experimental process is how various aspects of the experimental set-up can lead to a number of different questions. One such questions relates to the property of flame to ‘mix’ or not with other substances (tangible or pneumatic).³¹ The other relates to the ‘natural’ shape of flames being medium-dependent.³² NO offers a variation of the experimental set-up:

...take a small metal vessel and put a lighted wax candle in it; put the vessel in a bowl and pour in a fair amount of spirit of wine but not enough to reach the vessel’s mouth, and then light the spirit. This latter will give you a more bluish flame, the candle light a yellower. Se therefore whether the candle flame... keeps its pyramidal form, or whether it does not rather tend to become spherical, since nothing can be found there to destroy or compress it. (NO, OFB XI 337-9)

We can presume that in this form the experiment allows some air between the two flames (and therefore they are not immediately extinguished). Bacon classifies it as a crucial instance destined to “illuminate the question with flames of two colours” (OFB XI 337). In other words, the main question of this experiment in this form is to study the shape of the flame and to infer some medium-dependence of the flame. If the flame-within-a-flame is orbicular instead of pyramidal,³³ it means that the ‘regular’ pyramidal shape of flame we are all accustomed to is not a ‘natural’ shape, but merely a result between the interaction of the flame and surrounding air. It is here that Bacon’s speculative

³¹ Such strings of experiments are developed in SS I 366 ff. (burning spirit of wine mixed with various tangible substances and measuring the burning time), SS I 30 (mixing flame with gunpowder and air to create blasts). In NO we can also find exploratory experiments directed towards discovering the various degrees of heat of different kinds of flames. See NO in OFB XI 245 where Bacon offers an ordered table of the power and degree of heat (temperature) of flames extending from spirit of wine (the softest) to gunpowder and Greek fire (the highest degree of heat). Other experiments are investigating the process of burning (of various substances) and the shape of the flame. See NO, OFB XI 335.

³² See NO OFB XI 265, 269, 337-9.

³³ The experiment in SS also states that the flame-within-a-flame is five time larger than the same flame burning in air.

cosmology comes to play a role in the exploratory experimentation. Both the explanation of the orbicular shape of the flame-within-a-flame and the modeling aspect of these experiments are theory-informed.³⁴ This is even more clear when the same experiment is propounded as a model; a table-top model of a star. Here is how the experiment concludes, in SS:

By all which it should seem that the celestial bodies (most of them) are true fires or flames, as the Stoics held; more fine (perhaps) and rarefied than our flame is. For they are all globular and determinate; they have rotation; and they have the colour and splendor of flame; so that flame above is durable and consistent, and in his natural place; but with us is a stranger and momentany, and impure. (SS I 31, SEH II 353).

This paragraph represents the conclusion of Bacon's exploratory experimentation with the flame-in-a-flame; it claims that there are a number of relevant similarities between the parameters of the experiment and the properties of celestial objects. The orbicular flame of the model has the same shape and motion ascribed to celestial bodies, it rotates and twinkles, it is durable and consistent, spherical and white in color. Are these qualities enough to ground the analogical extension of the experimental results from the table-top model into a natural history of the heavens? This question is addressed by Bacon in another of his writings, DGI, precisely in the context of the 'proper' way to develop a natural history of the heavens. There the same experiment of the flame-within-the-flame is used to develop different questions. One of them is whether one can see lucid objects through flames. The traditional two sphere cosmology was answering this question in the negative. In fact, the impossibility of seeing a flame-within-a-flame was given as a powerful argument against the existence of the 'enflamed' ether. Bacon asserts:

³⁴ They are however not theory-driven. The distinction between exploratory and theory-driven experiments focuses on the specific ways in which experiments depends on theory. For example, theoretical interventions can be at the level of background knowledge, they can inform the concepts used to describe what happens in an experiment etc. For a discussion on the ways in which experiments can be theory informed see for example: Michael Heidelberger, *Theory-Ladenness and Scientific Instruments in Experimentation*, in Hans Radder, ed., *The Philosophy of Scientific Experimentation*, Pittsburgh: University of Pittsburgh Press, 2003, 138-151 and Ken Waters, *The Nature and Context of Exploratory Experimentation*.

There is, however, no reason why something lucid should not be a transparent medium for the transmission of a stronger light... But we see that flame itself is a transparent medium, even for transmitting the species of an opaque body, as is shown in the wick of candles; much more for transmitting the species of an intenser light. Even among flames some are more translucent than others. (DGI OFB VI 150-1)

The result of the flame-in-a-flame experiment is in this case refuting a received opinion and showing the possibility of conceiving it differently. The experiment also is treated as a model, but this time the modeled phenomenon is different: not a star, but the phenomenon of *aurora borealis* – it is thus replicated with the flame-within-a-flame experiment.

By the same token, bright beams are quite often seen through the heaven, giving out manifest light and markedly illuminating the darkness of the night, through whose bodies it is nevertheless possible to see the stars. (DGI OFB VI 151)

This process of modeling is of course not theory-free. However, the relation between Bacon's speculative cosmology and his modeling experiments is not as straightforward as usually assumed. The flame-within-a-flame is not a mere illustration of the theory stating that there is a fiery ether equally distributed through the universe, carrying with it the 'flames' of the celestial bodies. It is a complex experimental situation fulfilling more than one function, and exploited to ask diverse questions regarding the nature of the flame, the medium-dependence shape of a flame, the possibility of modeling celestial phenomena such as *aurora borealis* or the telescopic observations of celestial bodies.

Conclusion

As we have seen in the examples above, experiments play more than one role in Bacon's complex construction of natural history. They illustrate and exemplify; they serve as

classificatory devices, they are constantly used to put together – sometimes in a totally unexpected manner – phenomena belonging apparently to very different realms under the common (working) definitions of concepts such as: ‘winds’, ‘maturation’, ‘desiccation’, ‘liquefaction’ etc. The principles behind the scheme of classification are provided by Bacon’s matter theory and by his methodological rules, developed under the name of *experientia literata*.³⁵ If we classify all motions of the air as winds, the device called ‘weather-glass’ and various experimental variations of the same experimental set-up are facilitating the classification process and add unexpected members in the classification properly speaking. Moreover, experiments can play the role of the model: in the same way (to quote Bacon again) that Aristotle’s politics begins with the ‘model’ of the family, artificial models of rainbows through prisms or winds created by bellows can provide a smaller-scale and simpler phenomenon to begin our inquiry with. A word of caution, however: Bacon’s models are not simplified and idealized versions of the phenomena in the same way in which Galileo’s inclined planes are providing models for the free fall. Bacon’s artificial models are extremely complex ‘real’ phenomena and not idealized reconstructions. Their main use is not to represent a step in the treatment of a larger problem. Their main use is to provide ministrations for the senses, intellect and imagination. They have a heuristic purpose; they free the mind from received prejudices and theories, provide ‘helps’ and ‘instruments’ in the process of discovery, offer classificatory schemes and devices, act as instruments in the ‘art’ of questioning nature – and much more. Experiments also provide basis for analogy, through modelling. At least *some* Baconian experiments do. This should therefore be a *raison de plus* to direct our inquiry into a more thorough exploration of Baconian experimentation and Baconian natural histories.

Abbreviations:

SEH = *The Works of Francis Bacon, Baron of Verulam, Viscount St. Alban, and Lord High Chancellor of England*. (14 vols.) Collected and edited by James Spedding, Robert

³⁵ On Bacon’s *experientia literata* see also Dana Jalobeanu, *The Hunt of Pan*, Laura Georgescu, A New Form of Knowledge: *Experientia Literata, Society and Politics* 10, 2011, 104-137 and Jalobeanu, Core experiments, natural histories and the art of *experientia literata*.

Leslie Ellis and Douglas Denon Heath. London: Longman, 1857–1874 (facsimile reprint Stuttgart-Bad Cannstatt: Frommann-Holzboog, 1961–1963).

OFB = *The Oxford Francis Bacon*. (15 vols. planned, 6 vols. to date) General editors: Graham Rees and Lisa Jardine (1996–2006); Sir Brian Vickers (2006–). Oxford: Clarendon Press.

DGI = *Descriptio globi intellectualis*

HDR = *Historia densi et rari*

HNE = *Historia naturalis et experimentalis*

HV = *Historia ventorum*

HVM = *Historia vitae et mortis*

SS = *Sylva Sylvarum*