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CONSTRUCTING NATURAL HISTORICAL FACTS

BACONIAN NATURAL HISTORY IN NEWTON'S FIRST PAPER ON LIGHT AND COLORS

Dana Jalobeanu[*]

The peculiar structure of Newton's first published paper on light and colors has been the subject of an astonishing diversity of readings: to date, scholars still do not agree as to what Newton wanted to prove in this paper or how he proved it.[1] The structure of the paper is far from transparent. It consists of two very different parts: a historical account of what Newton called his "crucial experiment," and a "doctrine of colors" consisting of thirteen propositions and an illustrative experiment. Equally debated has been the "style" of Newton's demonstration.[2] Newton begins the first part with an extensive historical account of how he became interested in the "celebrated phenomena of colors" and later reached one of its major results: that the shape of the spectrum refracted

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[1] The paper has been read, in turns, as a formal blunder of a young upstart who dared to make a clear break with the mitigated skepticism and anti-dogmatism of the Royal Society, and as a brilliant exercise of rhetoric aiming to rewrite in the "scientific style of the day" the results of six long years of optical research. The reason for the exercise of rhetoric has also been the subject of fierce debates. For the first view, see Bechler (1974). For a representative selection of papers debating the second view, see Schaffer (1989), Shapiro (1996), Zemplén and Demeter (2010). See also Lohne (1968).

[2] Following I. B. Cohen (1982, 1980), a general trend in Newtonian studies has been to distinguish between the "mathematical style" of the *Principia* and the "empirical style" of the *Opticks*. This distinction was very much in accord with the famous Kuhnian (1977) divide between "mathematical" and Baconian traditions in early modern Europe. In contrast, more recent articles have tried to establish an opposite view, arguing for a unity of style in Newton's methodology. This has been done either by giving a more general interpretation of Newton's "deduction from phenomena," or by emphasizing the strong empirical component of Newton's *Principia*. For the first, see Worall (2000); for the second, see Ducheyne (2011), Harper (2011), and Stein (2002).

through a prism is oblong rather than circular. It is by all accounts a weird historical reconstruction of more than six years of optical research and two sets of very sophisticated optical lectures taught at Cambridge in 1670–1672.[3]

There is even less agreement as to why Newton chose to write his first published paper in this peculiar style, employing elements borrowed from mixed-mathematics and natural history. Some scholars have seen it as an attempt to reconstruct an earlier discovery in terms of Baconian induction,[4] or even an attempt to explicitly tailor new discoveries to follow the methodological prescriptions of the Royal Society.[5] Others saw it as a proof that Newton used experiments in an entirely new way.[6]

Such diversity of opinions is hardly surprising. On the one hand, the issue has wider implications on the thorny problem of Newton's method. It raises important methodological and epistemological questions such as the relation between theory and experiments, "facts" and inductive generalizations, and natural history and natural philosophy. On the other hand, reading Newton's first paper in historical context raises intricate questions regarding historical influences. How much of Newton's early experimental style was indebted to, and influenced by, the Baconian method of natural history and by Baconian experimental practices of the early Royal Society?

To further complicate matters, the methodological and the historical aspects are often interconnected. In order to understand Newton's use of terms and the peculiar form of his demonstration, a contextual reading is often unavoidable. Unfortunately, most contextual analyses have so far worked with idiosyncratic views of Baconian method and Baconian experimental philosophy originating in the famous Kuhnian

[3] See for example the debate between Shapiro and Shaffer on the reasons and extent of this reconstruction, Schaffer (1989), Shapiro (1980, 2008).

[4] Dear (1985), Lohne (1968).

[5] In an influential article, Feinghold has considered Newton's first publication as written in a style that pays lip service to the standards of writing imposed by the early Royal Society, standards that Newton never liked and soon abandoned in order to propose an alternative, "mathematical" style. For Feingold (2001), the divide between "mathematicians" and "natural historians" within the Royal Society best characterizes the Society's purpose and functioning and the debates sparked by Newton's first paper and Newton's subsequent withdrawal from discussions are seen as a proof that Newton "came to consider the Royal Society a forum inhospitable for his beliefs" (p. 84).

[6] In a series of papers and a book, Ben-Chaim argues that Newton uses experiments in a new way: not as aids or illustrations for a theory, but as tools and instruments of practical learning. Moreover, he argues, this transformation is coupled to a new 'scientific style,' in many ways similar to mid-seventeenth-century sermonical style. Ben-Chaim particularly investigates the similarities of Newton's scientific style with Wilkins' writings on the style of preaching. In this paper, I will endorse some of Ben-Chaim's conclusions regarding the transformation of the role and purpose of experiment, but also will give a different interpretation of Newton's "style" as more Baconian than is recognized by most contemporary Newtonian scholars. See Ben-Chaim (1998, 2004, 2001).

divide between traditional (mathematical) and Baconian sciences. Accordingly, such analyses saw Baconian natural history as a quite-random, theory-free activity of gathering "facts," in stark contrast with Newton's highly theoretical experimental philosophy.

Recent developments in the field of Baconian studies have seriously amended this traditional (Kuhnian) picture. Due to the seminal work of Graham Rees and his students, it has become impossible nowadays to neglect a certain "scientific" Baconianism, developed in Francis Bacon's late natural and experimental histories.[7] Important studies written in the past two decades have emphasized the complexity and theoretical structure underpinning Bacon's experimentation and his natural histories.[8] Moreover, Peter Anstey and Michael Hunter have shown that Bacon's natural historical methodology had a much wider influence upon seventeenth-century experimental natural philosophy (Newton included) than previously thought.[9]

My paper investigates the "Baconianism" of Newton's first published paper in the light of these recent developments in scholarship. My thesis is simple: in his paper, Newton used important elements of Baconian natural history. Although much remains to be done, it has become clearer due to the above-mentioned research that Baconian natural histories are not simply storehouses of "facts" and materials for the building of a reformed natural philosophy. They have a complex structure and contain inbuilt theoretical and methodological elements. For example, they contain an open-ended (often explicitly collaborative) series of observations and experiments, often developed one from the other through variations of experimental parameters. They contain provisional and preliminary theoretical results (often called rules, or axioms), methodological and epistemological considerations, and refutations of established theories.

My aim in this paper is to identify some such elements of Baconian natural history in Newton's first paper on light and colors. I begin by showing that the construction of Newton's paper follows some of Bacon's rules for writing a natural history. I will then show that the way in which Newton presents the development of his crucial experiment has features similar to Francis Bacon's art of utilizing experiments for producing knowledge in his natural and experimental histories. I exemplify my general claim by a particular example taken from Francis Bacon's *Historia densi et rari* (1658). I show that there are interesting similarities between the ways in which Bacon and Newton use strings of experiments of successive generality in order to construct and establish (beyond any reasonable doubt) "phenomena" and theoretical results.

[7] See Graham Rees' introductions to Volumes 12 and 13 of the new *Oxford Francis Bacon* edition (Bacon 2007, Bacon 2000). I will hereafter refer all quotes from Bacon to this edition, abbreviated *OFB*.

[8] For more detailed discussion and bibliographical references, see Corneanu, Giglioni, and Jalobeanu (2012).

[9] Anstey (2004), Anstey and Hunter (2008), Hunter (2007).

It is important to note that the focus of this historical and philosophical reconstruction is not primarily to establish historical influence. Newton owned a copy of Bacon's *Historia densi et rari* and most probably read it.[10] The experiment I am going to discuss is dog-eared in his copy. However, as with many other experimental natural philosophers of the late seventeenth-century, Newton reflected critically and creatively on Bacon, and developed his own particular brand of Baconian natural history. In this, he closely followed Robert Hooke's research, as reported in the section on colors from *Micrographia* (1665). In the last part of this article, I show that reading Newton's paper as a contribution to the early 1670s lively epistemological and methodological debate over the purpose, methods, and extent of Baconian natural history (and attached methodology of experimentation) clarifies some of the early critiques Newton's paper received from his correspondents and contenders (most notably from Robert Hooke).

AQ: The referenced source in Chapter 2, Footnote 10 ([H109]) will need to be updated.

2.1 NEWTON'S HISTORICAL ACCOUNT AND METHOD OF INQUIRY: FROM THE INVESTIGATION OF THE SPECTRUM TO THE CRUCIAL EXPERIMENT

Newton's paper has two clearly distinguished parts: a "historical" account culminating with the experimentum crucis and the establishment of the 'fact' that light is made of rays of different refrangibility, and his "new doctrine" of light and colors exposed in thirteen propositions. The second part ends with an illustrative experiment aiming to show the possibility of "recomposing" white light. Although each of the two parts has its own peculiarities, the "historical" account has raised most questions and has produced most puzzles.[11]

The paper begins thus:

> To perform my late promise to you, I shall without ceremony acquaint you, that in the beginning of the year 1666… I procured me a triangular glass-prisme, to try therewith the celebrated phenomena of colours. And In order thereto having

[10] See the entry **[H109]**, Bacon, Francis. Opuscula varia posthuma, philosophica, civilia, et theologica, nunc primum edita. Cura & fide G. Rawley. Una cum nobilissimi auctoris vita. 8°, Londini, 1658 (Harrison 1968). According to Harrison, the book is dog-eared at page 17, which is precisely at the experiment discussed in the fifth section of my paper.

[11] The peculiarity of this historical account has been characterized by Schaffer (1989) as follows: "In the letter to Oldenburg of February 1672 Newton selected some of his earlier trials, rewrote his autobiography, omitted many important details—notably those on prism quality and design—and revised some of the lessons these experiments were supposed to teach. The experimentum crucis was a simplified and revised form of large numbers of experiments given in the 3rd and 6th of Cambridge lectures" (p. 84).

> darkened my chamber, and made a small hole in my window-shuts, to let in a convenient quantity of the Suns light, I placed my Prisme at his entrance, that it might be thereby refracted to the opposite wall. It was at first a very pleasing divertisement, to view the vivid and intense colours produced thereby; but after a while applying myself to consider them more circumspectly, I became surprised to see them in an oblong form; which, according to the received laws of refraction, I expected should have been circular.[12]

Newton recounts here in an abridged form a multitude of experiments—all quite well known to his contemporaries—and establishes the experimental fact to be the subject of further investigation: the oblong form of the spectrum. Newton's adversaries in the subsequent debates (Hooke, Pardies, Lucas, etc.) were not all able to replicate the oblong spectrum, mainly because in order to obtain the spectrum and not a colored "prismatical iris,"[13] both the prism and the screen have to be placed in certain positions, yet Newton does not note precise positions. Rather, in the development of his historical account, he presents his reader with a string of experiments generated through experimental variation of various parameters: the thickness of glass, the dimension of the hole in the curtain admitting light, and the position of the prism with respect to the hole. As a result of this first string of experiments, Newton concludes that the effect discovered does not depend on any of the above parameters, and that "the fashion of the colors was in all these cases the same."

In a second string of experiments, Newton addresses a more theoretical question: Is the phenomenon produced only when a ray of light is decomposed by a prism? Perhaps some "contingent irregularity" of the prismatic refraction is the cause of the oblong spectrum. This question is investigated through a more elaborate experiment, one with two prisms: the first prism decomposes the incoming white light, the second receives the spectrum and produces, on the screen, an "orbicular" shape.[14] Newton concludes at this point that "what ever was the cause of that length, 'twas not any contingent irregularity" [in the prism].[15]

[12] Newton (1672a, pp. 3076–3077).

[13] Which is what Robert Boyle has "established" as a result of the experiment, in his natural and experimental history of colors. For Boyle's prismatic experiments, see Boyle (1664, p. 191ff.). Boyle's prismatic experiments are recorded under the general (Baconian) heading "Promiscuous Experiments about Colors."

[14] Instead of elongating the oblong shape further, the introduction of a second prism seems to have a "contrary" effect, re-creating the orbicular shape one expects to encounter in the first place. This is an ingenious way of generalizing the discussion beyond mere prismatic refraction. It allows Newton to claim that whatever is the cause of the oblong shape in the first place has to do with the properties of light and not with prismatic refraction.

[15] Newton (1672a, p. 3076).

A third string of experiments has to do with the variation of another experimental condition: the angle of incidence of rays coming from "divers parts of the Sun." Interestingly enough, these strings of experiments conclude with a rather unexpected theoretical result: a refutation of Descartes' corpuscularian theory of light. Without mentioning Descartes by name, Newton claims that light cannot be made of corpuscles similar to "tennis balls" (like in the famous drawing of Descartes' *Dioptrics*) for the simple reason that the "oblique passage" of such tennis balls would encounter more resistance on one side than on the other:

> Then I began to suspect, whether the Rays, after their trajection through the Prisme, did not move in curve lines, and according to their more or less curvity tend to divers parts of the wall. And it increased my suspition, when I remembered that I had often seen a Tennis ball, struck with an oblique Racket, describe such a curve line. For, a circular as well as a progressive motion being communicated to it by that stroak, its parts on that side, where the motions conspire, must press and beat the contiguous Air more violently than on the other, and there excite a reluctancy and reaction of the Air proportionably greater. And for the same reason, if the Rays of light should possibly be globular bodies, and by their oblique passage out of one medium into another acquire circulating motion, they ought to feel the greater resistance from the ambient Æther on that side, where motions conspire, and thence be continually bowed to the other. But notwithstanding this plausible ground for suspition, when I came to examine it, I could observe no such curvity in them.[16]

At this point of the paper, Newton introduces his experimentum crucis, which can also be viewed as a supplementary construction added to the first experimental setup: the spectrum decomposed by the first prism is sent not onto a screen but onto two pierced screens and parts of it are further refracted using a second prism. Newton condenses into a very short description (with no geometrical figure attached) a series of experiments in which, by rotating the first prism, various regions/colors of the initial spectrum are further decomposed by a second prism and seen at various locations on a third screen. The results of the experimentum crucis are expressed rather obscurely in the following way:

> And I saw by the variation of those places [on the final screen], that the light, tending to that end of the Image, towards which the refraction of the first Prisme was made, did in the second Prisme suffer a Refraction considerably greater then the light tending to the other end.[17]

[16] Newton (1672a, p. 3078).
[17] Newton (1672a, p. 3079).

As Stein (2004) has shown, the awkward way in which Newton expresses his major result is mainly due to his struggle to describe the experiment and the experimental fact without speaking about colors. What Newton claimed to have observed as a result of his experimentum crucis was how the change of colors incident on the second prism affected the deviation of the image on the third screen: the red part of the spectrum, for example, was less deviated than the violet part. From this Newton concluded that "the true cause of the length of that Image [the oblong form of the spectrum] was detected to be no other than that Light consists of Rays differently refrangible, which, without any respect to a difference in their incidence, were, according to their degrees of refrangiblity, transmitted towards divers parts of the wall."[18]

It is quite interesting that what we take (in light of Newton's subsequent work on optics) to be the main theoretical result of the paper is expressed in rather obscure terms and is not developed and explained. The claim that light consists of rays with different degrees of refrangibility is embedded in a "history": multiple series of experiments, experimental results of increased generality, methodological considerations, descriptions of the experimental setups, and practical consequences followed by what Newton himself describes as a "digression," or a history of the idea, plan, and construction of the reflecting telescope presented to the Royal Society in the same year (1672).[19] This move in Newton's paper has often been portrayed as sheer rhetoric: Newton attempted to give weight to what is at best a sketchy demonstration by showing its practical/technical applications. The overall character of the paper is not made clearer by the fact that what follows after the practical "digression" is yet another kind of content, namely his "new doctrine" of colors, apparently unrelated to the first part of the paper, summarized in thirteen propositions without demonstrations.

All in all, peculiarities of structure and style apart, the first part of Newton's paper seems to claim that strings of experiments give rise to a number of results of increased generality. Modern readers tend to distinguish among Newton's results, saying that some are experimental results (the oblong form of the spectrum), some are theoretical results (the proposition "light consists of rays of different refragibility") and some are practical results (the reflecting telescope). This is not, however, how Newton's paper presents them. They are introduced as experimental results of increasing generality, culminating with the causal explanation of the oblong spectrum.[20]

[18] Ibid.

[19] Newton (1672b).

[20] Newton referred often to the factual character of this discovery in his correspondence with Hooke and others. Even if subtle inconsistencies appear in the way he explained the results of his crucial experiment at one stage or another in his debate with Robert Hooke, or father Lucas, they are mostly connected with the question whether his theory of colors is intrinsically coupled with that of light. See Zemplén and Demeter (2010).

Although arguably peculiar for modern readers, this expositive and demonstrative structure was widespread in the experimental research of the early Royal Society. Take for example Robert Hooke's famous investigation of the same "celebrated phenomena of colors" in *Micrographia*. What is entitled "Observ. IX" of *Micrographia* has indeed a very similar structure. It begins with the presentation of curious phenomena of spectral decomposition in *Lapis specularis*, or Muscovy Glass, "a body that seems to have as many Curiosities in its Fabrick as any common Mineral I have met with."[21] Because of its curious nature, Hooke claims that the "history" of this body "does afford better ways of examining" the production and variation of colors than the study of peacocks' feathers. Hooke uses "history" here with the same meaning as Newton, Bacon, and most of their contemporaries, i.e., in the sense of careful and systematic inquiry.[22] Like Newton, his history also begins with "an exceedingly pleasant and not less instructive Spectacle":

> And that is, if curiosity and diligence be used, you may so split this admirable substance [Muscovy Glass] that you may have pretty large Plates . . . . Each of them appearing through the Microscope most curiously, intirely and uniformly adorned with some one vivid colour: this, if examined with the Microscope, may be plainly perceived to be in all parts of it equally thick. Two, three or more of these lying one upon another, exhibit oftentimes curious compounded colours, which produce such a Compositum, as one would scarce imagine should be the result of such ingredients: As perhaps a faint yellow and a blew may produce a very deep purple. But when anon we come to the more strict examination of these Phenomena, and to inquire into the causes and reasons of these productions, we shall, I hope, make it more conceivable how they are produced, and shew them to be no other then the natural and necessary effects arising from the peculiar union of concurrent causes.[23]

In developing the subsequent "history," Hooke offers strings of experiments and observations leading to results of increasing generality. First, he demonstrates that the "phenomena of colors" (the appearance of "irises or colored lines"[24]) are not restricted to Muscovy Glass but can be reproduced with sufficiently thin plates made of any transparent substance.[25] After having established the "generality or universality of this

[21] Hooke (1665, p. 47).

[22] This is also the sense in which Renaissance naturalists used "natural history," following Pliny's *Historia naturalis*. For a discussion, see Jalobeanu (2012a).

[23] Hooke (1665, p. 49).

[24] Ibid., p. 50.

[25] Hooke does not limit the research to thin plates of glass, but inquires into the same phenomena produced in soap and glass bubbles, organic materials, watered steel, etc.; Ibid., pp. 50–51.

propriety," the history develops further with other, more complex strings of experiments destined to determine which parameters are relevant for the production of colors. Hooke establishes thus that the experimental result does not depend on the source of light,[26] on the matter of which the thin plate is made, or on the matter of the medium between two thin plates.[27] It is worth pointing out that Hooke's historical account also ends with a crucial experiment destined to refute Descartes' theory of the production of colors (of which, find more in the last section of this paper), after which Observation IX continues with a general "discourse" concerning the "nature of Light and Refraction." Although Hooke's text is dense and not separated by headings, its discursive structure is fairly clear and is astonishingly similar to the structure of Newton's first paper: a historical account composed of strings of experiments destined to prove experimental and theoretical results of increasing generality, a "crucial experiment," and a section positing an affirmative (in Hooke's case, also hypothetical) doctrine regarding the nature and properties of light.

This careful textual separation between "history" and "theory" (doctrine) and the particular ordering destined to create the impression that the doctrine/hypothesis is constructed upon natural history are other important features of Baconian natural history[28] that gets incorporated into the "scientific style" of mid-seventeenth-century experimental natural philosophy.[29]

In order to clarify these and other peculiar features of Newton's first paper, in the next section I offer a textual reconstruction of Bacon's conception of natural history and his method for producing natural histories. Then, I will turn to a particular example, putting in parallel Newton's and Bacon's experimental procedures.

2.2 THE CONSTRUCTION OF BACONIAN NATURAL HISTORIES

There is a persistent tendency among historians and philosophers of science to espouse a caricature view according to which Baconian natural histories are large collections of

[26] Repeating the string of experiments with various sources of light, from the light coming directly from the sun, to different angles of incidence, and finally to the light of a candle; Ibid., pp. 53–54.
[27] Ibid., pp. 50–53.
[28] One can find a very similar structure in Boyle. Boyle writes, for example: "I must desire that you would look upon this little Treatise, not as a Discourse written Principally to maintain any of the fore-mentioned Theories… or substitute a New one of my Own, but as the beginning of a new History of Colours, upon which, when you and yours Ingenious friends shall have Enriched it, a Solid Theory may be safely built" (Boyle 1664, pp. 88–89).
[29] Anstey (2002, 2004, 2005).

observations about nature, mostly repetitive and purely qualitative.[30] In the past decades, however, substantial studies have shown that this caricature view is false in almost all its details. Bacon's natural histories are often quantitative,[31] they make use of instruments and elaborated experimental techniques,[32] they are often generated from a limited number of privileged and relevant experiments, and have a rich underlying theoretical structure.[33] Moreover, Bacon often reflected upon how to construct natural histories and wrote several methodological and philosophical texts on the very procedure of generating experiments and recording such histories.[34] In one of them, entitled "Preparative to a Natural History,"[35] Bacon enumerates a set of ten rules or "general instructions" on how to write what he calls a "primary natural history" (or "mother history"),[36] i.e., the simplest and most general form of natural history that can serve as basis for further work in natural history and natural philosophy alike. The same work also contains hints at more elaborate, more theoretical natural histories halfway between this "primary" history and natural philosophy, properly speaking: what Bacon used to call "a middle term, so to speak, between history and philosophy."[37] These rules/directions are not always clear partly because Bacon often shifts between the two meanings of natural history mentioned above,[38] and partly because they have to be read in conjunction with certain aphorisms from the first and second parts of the *Novum organum*. To the extent that their meaning can be reconstructed from Bacon's writings, it seems that such directions

[30] The view originates most probably in the influential Kuhn (1977). It can still be found with slight emendations in Daston (1991), Dear (1995, 2006), and Findlen (1995).

[31] See for example Pastorino (2011), Pérez-Ramos (1990), and Rees (1985).

[32] Stewart (2012), Weeks (2008).

[33] Jalobeanu (2010b, 2012a, 2013), Zagorin (1998, pp. 113–129).

[34] Jalobeanu (2012a). I have divided Bacon's natural historical works into works of natural history and works about natural history. Representative natural histories are the Latin natural histories that Bacon wrote in the last five years of his life under the generic title *Historia naturalis et experimentalis*. The finished ones are *Historia ventorum, Historia densi et rari*, and *Historia vitae et mortis*. There also exist a number of fragments and manuscripts of other natural histories in various stages of completions. As for Bacon's works about natural history, I take as representative works like "Parasceve" ("Preparative to a Natural History"), the fragments on natural history from the preface to *Instauratio magna, Distributio operis*, the preface to *Historia naturalis et experimentalis*, the lists of 130 histories appended to *Novum organum*, the fragment called "Descriptio globi intellectualis" and the fragments on natural history from *De augmentis scientiarum*. Also, an important work about natural history is *New Atlantis*.

[35] *Parasceve ad historiam naturalem* was a part of the 1620s edition of Instauratio Magna. It contained two parts: *A description of natural and experimental history of the kind fit to serve as a plan for the basis and foundation of the true philosophy*, and *Aphorisms on the construction of a primary history*. It was also translated in English and published in 1670 both separately and as a part of Bacon (1670).

[36] *OFB*, vol. 11, p. 453.

[37] As for an example in *Descriptio globi intellectualis, OFB*, vol. 5, pp. 109–110.

[38] For the evolution of Bacon's conception of natural history, see Anstey (2012).

for writing natural history govern both the process of experimentation (i.e., production of natural historical 'facts') and the process of recording such experimentation.

AQ: Please verify that where "instances of special power" is used generally, the term is lower cased; as well, in specific references to Bacon's list of "Instances of Special Power," the term is capitalized and retained in quotations. Please review these edits and, if necessary, apply any corrections.

For Bacon, a natural and experimental history begins with specially selected and highly relevant sets of experiments of light, i.e., "experiments of no use in themselves but which only contribute to the discovery of causes."[39] Such experiments are not mere observations, but complex procedures through which the experimenter vexes Nature, stripping "the mask and veil from natural things which generally lie concealed or hidden beneath a variety of shapes and outward appearances."[40] They involve a long, painstaking, often repetitive process of counting, weighting, measuring, defining, or, as Bacon puts it "a good marriage of Physics and Mathematics."[41] Constructing a natural history also implies a selection; the experimenter has to choose, from the multitude of natural phenomena, the relevant trials and the productive experiments.[42] Bacon implies that there are, among the experiments of light, particularly informative experiments, experiments able either to illuminate or improve the senses, or able to act as interesting shortcuts in the attempts to understand nature, or which are simply closer to theoretical generalizations. They can be of great help for the investigator of nature. Such are what he calls prerogative instances, or instances of special power (ISP).[43] An important rule for constructing natural histories is to look for precisely such instances:

> But for the selection of the most important instances of every sort (which should be sought out and as it were tracked down with all the determination at our command) we must look to our Instances with Special Powers.[44]

[39] *Novum organum*, Book I, Aph. 99, *OFB*, vol. 11, 158–159. Bacon's own natural and experimental histories are all centered upon such sets.

[40] *Novum organum*, Book I, Aph. 5, *OFB*, vol. 11, p. 463.

[41] *Novum organum*, Book I, Aph. 7, *OFB*, vol. 11, p. 465. See also *OFB* vol. 11, pp. 366–368: "The powers and actions of bodies are circumscribed and measured either by point in space, moment of time, concentration of quantity, or ascendancy of virtue, and unless these four have been well and carefully weighed up, the sciences will perhaps be pretty as speculation, but fall flat in practice." On the quantitative aspects of Bacon's natural histories, see Pastorino (2011), Rees (1985, 1986).

[42] This selective procedure is described in *Sylva Sylvarum* (Bacon 1627, p. 7) in the following way: "The rejection which I continually use of experiments (though appeareth not) is infinite."

[43] ISPs are particular classes of experiments of light, identified by Bacon as useful shortcuts in the exploration of nature. They can play a variety of roles in the construction of natural histories, but they are theoretically oriented and can lead from natural history to the next stage, the development of a more theoretical natural philosophy. The doctrine of ISP is among the unfinished parts of Bacon's programs and all that is left of it is the long list of twenty-seven ISPs ending the second book of *Novum organum*. However, Bacon successfully used some such ISP in the development of his own particular natural and experimental histories. In the following example (see next section), the experiment I discuss belongs to a class of ISP called instances of the lamp. For a more general discussion on how experiments of light and ISPs enter into a natural history, see Jalobeanu (2011, 2013).

[44] *Novum organum*, Book II, Aph. 5, *OFB*, vol. 11, p. 465.

The list of the "Instances with Special Powers" constitutes the bulk of the second book of *Novum organum*; an unfinished part of the work, rather obscure and rarely visited by the modern scholar.[45] They are, in Rees' words, "labor-saving devices or shortcuts" providing "logical reinforcement to induction."[46] But ISPs are also model examples of relevant experiments that the investigator can successfully use in his construction of natural histories. Some classes of ISPs can be collected as sets of particular natural histories right from the start; others require more elaborated treatment. They can be tools (i.e., the telescope, microscope, prism, other surveying instruments), experiments of various degrees of complexity, or even natural objects themselves.[47] Prisms figure as IPS too:

> For example, if you are investigating the nature of Colour, Solitary Instances are prisms, clear gems which show colours not just inside themselves, but outside on a wall, dew too etc.[48]

Therefore, a natural history of colors will definitely make use of, maybe even begin with, experiments devised with prisms.[49] There are several classes of ISP playing important parts at various stages in the production of a natural history. Some can constitute the very beginning of a natural history: such are the solitary instances, or the instances of the lamp. Others are of particular interest once a natural history takes off the ground and must examine conflicting interpretations of a given phenomenon. Such are the celebrated "crucial instances" for which Hooke coined, in *Micrographia*, the name "crucial experiment."

In additions to the abovementioned rules, the writing of natural history has also some "extra useful features" of a more theoretical character.[50] A natural history should

[45] Rees, "Introduction: The *Novum organum* in Context," *OFB*, vol. 11, p. lxxvii–xcii.

[46] *OFB*, vol. 11, p. lxxxviii. As Rees has shown, most of the ISPs are examples "drawn from bodies of ideas which Bacon had set down in a coherent form in earlier, and sometimes unfinished treatises—for instance Phenomena universi, De fluxi et refluxu maris, Descriptio globi intellectualis, Thema coeli . . . These works B[illegible] withheld from publication, but he chose to disassemble their doctrines before cautiously infiltrating the disjecta membra into Novum organum. In Novum organum these materials were not fragmentary but deliberately fragmented. To exemplify ISPs Bacon robbed out his system of theories about the nature of things and, publishing them for the first time, set them forth dispersedly, and in such a way that perhaps he alone knew of the connective tissue holding them together" (Rees, *OFB*, vol. 11, p. lxxxiii).

[47] The loadstone is an exemplar of a 'monadic instance,' an object interesting enough by itself to be the starting point of a natural history.

[48] *Novum organum*, Book II, Aph. 22, OFB vol. 11, p. 273.

[49] Prisms are also methods of producing artificial rainbows, for Bacon, and hence instruments for studying natural phenomena in better experimental conditions than in nature.

[50] *OFB*, vol. 11, p. 469.

contain "questions" (queries) to direct the investigation and explanations of the experimental setup "so that people will be free to make up their minds whether it is trustworthy or not, and also that their industry will be stirred up to look for more exact ways (if possible) of doing experiment."[51] The natural history should also contain theoretical and methodological observations as well as rules directing the researcher—rules "which are nothing other than general and catholic observations."[52] In addition to what can be extracted from direct observation and experiment, natural histories can also contain summaries, glosses, provisional rules and axioms, and sometimes refutations of the received opinions and theories concerning certain phenomena.[53] What is important, however, is that all these elements are kept separate in the text, so that the reader can distinguish between them. In his Latin natural histories (*Historia ventorum*, 1622; *Historia vitae et mortis*, 1623; *Historia densi et rari*, 1658) Bacon used titles, marginalia, and up to six different fonts in order to distinguish between the various elements discussed above.

Last but not least, natural history should contain provisional rules (*Cannones mobiles*) or 'imperfect axioms' obtained in the course of inquiry. Such rules are not definitive laws of nature but provisional law-like regularities, or rules, obtained through experimentation that, in Bacon's own natural histories, come at the very end of the investigation. They are also carefully distinguished from the rest, and they are placed at the end of a natural history, in a list of propositions followed by commentaries.

Therefore, a natural and experimental history is not any collection of facts or experiments, not even of experiments topically organized, but a collection of relevant experiments generated in a controlled manner, according to the "true order of experience."[54] Furthermore, the results are "ordered and digested" according to the above-mentioned set of rules and directions.

2.3 "THE TRUE ORDER OF EXPERIENCE": *EXPERIENTIA LITERATA* IN THE PROCESS OF DISCOVERY

For Bacon, one of the major impediments to the advancement of learning was the lack of a proper method of discovery. All traditional "manners of discovery" relied more on chance than on pure knowledge. Chance discoveries obtained by "mere experience"—by 'groping in the dark'[55]—were no better for Bacon than "that which the brute beasts

[51] Ibid.
[52] *OFB*, vol. 11, p. 471.
[53] Ibid.
[54] *OFB*, vol. 11, p. 131.
[55] *OFB*, vol. 11, p. 100.

are capable… which is an extreme solicitude about some one thing, and perpetual practicing of it, such as the necessity of self-preservation impose on such animals."[56] Bacon's remedy is the invention of a new method that would transform "mere experience" into "experiment": "a different method, order and process for keeping experience going and advancing it."[57] Instead of random experience, he proposes experiments generated "according to a certain law, step by step and steadily."[58] The method or art for achieving this, apart from Bacon's famous interpretation of nature, is what Bacon calls *experientia literata*.

Learned (or literate) experience is an instrument through which the human intellect can proceed from one experiment to another, as if "led by the hand" in the dark.[59] It is experience— disciplined and "put into writing"—in fact, formalized into a set of "rules" or "modes" which, applied in order, can be used to generate new experiments in an orderly manner. Its major characteristic is that it always begins and ends in experiments, and, hence, it can constitute a good instrument for generating natural histories.[60] In a late methodological writing, *De augmentis scientiarum*, Bacon formulates eight "rules" or "modes" of literate experience, of which the first is the experimental variation of parameters. Other such modes are the extension of a given experiment (through repetition in a different experimental setup), the translation (into a different domain), inversion, or coupling of experiments, etc. Through such a procedure, the experimenter extends his field of research and generates new knowledge.[61] As a result:

> a great heap of discoveries still awaits us, a heap which can be brought to light not only by unearthing hitherto unknown operations, but by transferring, putting together and applying ones already known by means of what I have called literate experience.[62]

In fact, in the absence of a properly developed *interpretatio naturae* (or New Organon), literate experience is the only proper method of producing knowledge and our best

56 Bacon, *De augmentis scientiarum*, SEH IV, p. 408.
57 *OFB*, vol. 11, p. 100.
58 Ibid.
59 There is currently debate as to what precisely Bacon meant by *experientia literata*. In what follows, I will build upon previous research, as well as Georgescu (2011), Jalobeanu (2011, 2013), and Pastorino (2011).
60 There is another debate in the literature relating to the more general purposes of *experientia literata*, to its functioning as an instrument of recording, etc. For the purpose of this paper, these are fine details that do not affect what I intend to show.
61 Georgescu (2011), Jalobeanu (2013). The precise ways in which Bacon put this method to work is the subject of my forthcoming book, Jalobeanu (*forthcoming*).
62 *OFB*, vol. 11, p. 169.

hope of improving our knowledge. This, at least, is Bacon's position in his own natural histories, the Latin natural histories developed during the last five years of his life under the generic title *Historia naturalis et experimentalis*.[63]

2.4 BACONIAN EXPERIMENTATION

At this point, an example of literate experience at work would clarify what was new and potentially interesting in Bacon's natural and experimental histories. My example comes from one of the posthumous Latin natural histories, *Historia densi et rari*,[64] and involves Bacon's construction of one of the first tables of relative densities.[65] The table is the result of a long string of experiments which originate in a special kind of ISP, what Bacon called "instances of the lamp." They are special experiments able to extend the powers of the senses, or able to make visible the invisible processes and operations of nature. The experiment was developed relatively early in Bacon's career and figures prominently among the ISPs in the second book of *Novum organum* as well as in one of Bacon's most philosophical writings, *Phenomena universi*.[66] It involves constructing a cube of gold weighting one ounce, and two identical cubical recipients of silver that can contain the cube of gold. Then, the cube of silver—filled with the ounce of gold—is weighted against the empty recipient, with the help of a balance. Then, the empty silver recipient is filled with all sorts of substances. The relative weight at equal volume translates into relative densities. After repeating the weighting process with all the substances that he could lay his hands on, from quicksilver to "common earth," and from milk to fir wood, Bacon draws the resulting experimental fact: a long list of relative densities called "A table of the Coition and Expansion of Matter in Relation to Space in Tangible Bodies with a computation of the proportion in different bodies."

AQ: Would the reader, perhaps, benefit from the addition of a footnote?

The construction of this natural history is revealing. *HDR* begins with the table presented as the experimental result of an experimental procedure carefully described so that it makes replication possible. In fact, Bacon emphasizes that he has compiled the table "many years ago" and, therefore, there is "no doubt that a much more accurate one could be put together."[67] The description of the experimental procedure is followed

[63] In the preface to the *Historia naturalis et experimentalis* (1622; hereafter *HNE*), Bacon claims that even if his *Novum organum* would be finished, it would be useless without natural history, while natural history by itself can contribute to the growth of knowledge and the advancement of sciences. *OFB*, vol. 12, p. 11–12.

[64] Published by I. Gruter in 1658. Hereafter *HDR*.

[65] For a more detailed historical reconstruction of this experiment, see Pastorino (2011).

[66] *OFB*, vol. 6, also published by Gruter in 1658, in the same volume as *Historia densi et rari*.

[67] *OFB*, vol. 11, p. 49.

by a discussion concerning its limitations,[68] and further open-ended questions. In this way, the reader is encouraged to try for himself to replicate the experiment and, maybe, to move a step forward and add new lines to the table. The results of the experiments are set down in a list of seven observations. It is a very heterogeneous list, containing more than one category of results. The very first observation, for example, states that the experiment is important because, by showing that there is a finite variation of densities in nature, it can give us hope that we will eventually find a place in this table for all the known substances in the universe. On the other hand, we are told that the table is provisional and unfinished, and we should not assume that the "wrestling match" with nature is over. The second use of the table is to "dispel fantasies and dreams."[69] More particularly, Bacon uses the table to refute Aristotle's theory of the four elements: since there are many substances in the table that are heavier than "earth," it is clear that when the Peripatetics are talking about the elemental "earth," they are talking about a mysterious and unknown element "not available for mixture."[70]

In addition to refuting alternative theories, the experimental fact (the table) is also useful for refuting common opinions and common expectations (for example, the common opinion that hard bodies are especially dense), and hence, has a pedagogical and therapeutic aspect. Bacon claims that it benefits our mind to realize that many experimental results are other than one might assume in the first place; by working against our expectation, experimental activity has pedagogical, epistemological, and therapeutic features.[71] The table can be used to restrain and correct (*cohibenda et corrigenda*) common assumptions about the regularity and order of Nature.[72] Only the third observation provides what we would today consider the main result of the experiment, namely the fact that we can establish approximate quantitative laws of relative densities and, in particular, that the maximum variation of densities on the Earth is 32:1.[73]

[68] The smallness of the vessel and its cubical shape made it less suitable for substances that cannot be reduced to this shape and form. As a result, Bacon acknowledges that "as regards precise calculations, a certain degree of chance enters into the matter," *OFB*, vol. 13, p. 47. The discussion is entitled "Advices," and, as such, represents an important element in the construction of natural history (something that each reader has to take into consideration in order to be able to do his/her own experiments).

[69] "Nemo iatque expatietur, nemo fingat aut somniet." *OFB*, vol. 12, p. 48.

[70] *OFB*, vol. 13, p. 48–49.

[71] Ibid., p. 53. These aspects are strongly related to Bacon's beliefs that natural and experimental histories can also act as good medicines for the mind, that natural history is a serious instrument in fighting the idols of the mind, etc. See Corneanu (2011), Jalobeanu (2010a, 2012b).

[72] Ibid., pp. 49–51.

[73] The table is open ended, and Bacon clearly states that in the "bowels of the Earth" or in the heavens, one might find bodies with very different densities.

These observations are interspersed with what Bacon calls "Directions," i.e., new questions and suggestions for further experimentation. For example: Why is it that gold can be found not only in the depths of the Earth, but also on the surface, in the bed of various rivers? A line of investigation is open into the origins of such rivers: Do they proceed from "the bottom of mountains?"[74] More generally, we can investigate "loades in general, to see which of them are usually deeper and which nearer to the surface of the Earth; and in what geographical situation and soils they arise. . . ."[75]

Another category of results are called "incentives to practice," and they develop useful applications of the results obtained in the table. We are told, for example, that the table can be used as an instrument to discover the proportion of a substance in an alloy or a mixture.[76]

The "incentives to practice" are both extensions and applications of the table: we can inquire, for example, just by looking at the table, why there is a gap between stones and metals, or whether we can turn some of the substances in the table into some other substances, and through which procedures. What are the natural processes that modify density? Is condensation a "real" modification of density or a "pseudo-densation"?[77] In order to answer some of these questions, a new experiment is devised by a variation of the experimental conditions of the initial and setup: instead of weighting the substances in their 'natural' form, they are first reduced to different states of aggregation; they are, for example, transformed into powder, dissolved in other substances, or reduced to "liquors" or "spirits." As a result, a new table is constructed, followed by the same list of observations, directions, advices, and incentives to practice.

Both tables are, in Bacon's project, instances of a more complete table, still to be put together through experimental variation:

> The two tables above are pretty meager. The only precise table of bodies and their openings would be one which displayed the weight of the individual bodies first, then of their crude powders, next of their ashes, limes and rusts; next of their amalgamations, then of their vitrifications . . . then of their distillations . . . and of all other alterations of the same bodies; so that in this manner judgment may be formed of the openings of bodies and very closely knit connections of the nature in its whole state.[78]

74 *OFB*, vol. 13, p. 51.
75 Ibid.
76 Ibid., pp. 53–55.
77 Ibid., p. 55.
78 Ibid., p. 59.

Such a complete table would accomplish Bacon's purpose, which is to take a "census of tangible bodies family by family."[79] Its completion, however, is left to the reader, while Bacon moves to the second part of his natural history, which is the investigation of the "rare." A full reconstruction of the structure and purpose of Bacon's *HDR* is beyond my scope here. Instead, I propose to have a closer look to the relevant features of Baconian experimentation, as pictured in his strings of experiments leading to the construction of the table of densities.

Bacon treats his table as an experimental fact "constructed" at the end of a long, tedious, but carefully regulated process of experimentation. None of the results of the experimentation are treated as theoretical or speculative. They constitute experimental results of increased generality and their practical applications. Theoretical and methodological elements are also introduced, but they are carefully distinguished as "observations," "directions," "advices," or "incentives to practice."

However, all this does not imply that there is no theory at work in Bacon's natural histories. In fact, there is a fair amount of theoretical knowledge working at various levels in Bacon's construction of experimental facts. Some of this theory is spelled out in the provisional rules, but it is clear that at least some of the provisional rules, like the general principle of conservation of matter, are presupposed in the very construction of the experiment.[80] Equally presupposed in the experiment, although less obvious, is Bacon's theory of tangible and pneumatic matter,[81] according to which "dense" and "rare" bodies have opposing qualities. These theoretical elements, however, are not tested, but presupposed.

2.5 BACONIAN METHODOLOGY IN NEWTON'S PAPER ON LIGHT AND COLORS

Newton's first published paper observes a good number of Bacon's rules on how to write a natural history. It begins with relevant experiments (incidentally, prismatic refraction is also part of Bacon's long list of the "Instances of Special Power"), as is befitting a good natural history. It moves from one experiment to the other by varying the parameters and variables of the experiment, constructing in this way experimental series with results of increased generality. It uses experiments to refute alternative theories and hypotheses. It separates the natural history and the doctrine, and ends

[79] Ibid., p. 61.

[80] Manzo (1996).

[81] The way in which matter theory enters into Baconian natural history/natural philosophy has been thoroughly discussed in the recent decades. For a sample of representative writings, see Giglioni (2010), Rees (1996), and Weeks (2007).

the natural historical part with the results of the crucial experiment (re)constructed as a natural historical fact. If we compare Bacon's experimental procedure for constructing the table of densities with Newton's experimental procedure for getting to the results of *experimentum crucis*, we cannot fail to notice a number of striking similarities (as well as important differences). Bacon's table is the "constructed experimental fact," as Newton's result (that light is composed of rays of different refragibility) is an experimental fact obtained at the end of a carefully devised chain of experiments. The experimental procedure is sketched in both cases—detailed enough for the reader to attempt to replicate it, but not precise enough to make replication trivial. Taking up the experiment and attempted replication is, in natural history, a productive exercise for the mind and not a simply a procedure aimed at verifying evidence.[82]

Meanwhile, the controlled variation of experimental parameters is held responsible for the production of new experiments and experimental results. Another common feature is the multiple use of experiments. In both cases, experiments are said to refute competing theories. In both cases, the experiments are also said to produce useful results/applications, and such useful results are emphasized and explained (the possibility of determining the proportion of a substance in a mixture and the reflecting telescope, respectively). Last but not least, in both cases, natural history offers some causal explanations of the constructed facts without entering into metaphysical questions regarding the nature of density, or the nature of light. Needless to say, identifying similarities does not mean that there are no important differences between Bacon and Newton.

Despite such differences, however, there are good reasons to read at least the first part of Newton's paper as an instantiation of Baconian natural history. I conclude by showing how a number of the allegedly mysterious or unclear features of Newton's paper are clarified by my reading.

2.6 NEWTON'S READERS AND THE PROBLEM OF *EXPERIMENTUM CRUCIS*

It is clear from the parallels drawn above, that Newton's paper is not intentionally obscure or nontransparent, as has been sometimes claimed. Indeed, Newton gives what would have been seen as a good enough description of his experimental procedure to encourage replication and further work on the nature of refraction.[83] As a result, Newton's correspondents not only attempted to replicate, but devised their own

[82] On Bacon's use of experimentation in this way, see Jalobeanu (2011, 2013).
[83] The fact that such replication is difficult is not necessarily due to the phrasing of the paper. In this issue, I am standing with Shapiro (1996) against Schaffer (1989).

versions of Newton's experiments. Such is, for example, the paper published by Robert Moray in no. 83 of the *Philosophical Transactions* under the title "Some experiments proposed in relation to Mr Newton's Theory of light." Moray's experiments are generated through experimental variation of parameters applied to Newton's first experiment. For example, Moray asks what happens if the prism is partially covered with paper, or whether we can obtain a spectrum using light coming from Venus.

Another contentious issue regarding Newton's paper concerns the relatively small number of experiments reported. As we have seen, there is no requirement in a Baconian natural history to begin with a large number of experiments. Experiments are generated through *experientia literata* on a very limited, sometimes very small number of instances of special power. The multiplication of experiments is not necessary but can be done for pedagogical, practical, or "useful" purposes. Moreover, the first part of Newton's paper gives enough material for the reader to understand that the experimental variation can generate (and did generate, during Newton's optical researches) a very large number of experiments.

Similarly, as we have seen, Newton's introduction of his reflecting telescope as a potential application of his novel discoveries is a standard feature of Baconian natural history and not the rhetorical attempt of a newcomer to ingratiate himself with the worthies of the Royal Society.

Last but not least, reading the first part of Newton's paper as a Baconian natural history throws some light on the often-discussed issue of the crucial experiment. As we have seen, for Bacon, crucial instances play an important role in natural history.[84] They are experiments of particular relevance in discussing, evaluating, and refuting alternative theories.[85] They intervene when "the intellect is finely balanced" and "uncertain" which to choose between two or more alternative causal explanations.[86] In some cases, crucial instances provide powerful arguments to refute a theory and good reasons to accept its competitor. In some other cases crucial instances are no more than reasons to grow "suspicious," to "smell a rat, and go looking for other Crucial

[84] In the theory of crucial instances, Bacon ascribes for them a very important role in the interpretation of nature. Meanwhile, all the crucial instances presented there as examples are experiments he made use of in his natural histories in order to refute alternative theories.

[85] *OFB*, vol. 11, p. 319: "In the fourteenth place among Instances with Special Powers I will set down Crucial Instances [Instantias Crucis], taking the name from signposts set up at forks to mark and point out the parting of the ways. These I have also grown used to call Decisive and Judicial Instances and, in certain cases, Instances of the Oracle and Instruction." As all these names indicate, crucial instances play a very important role for Bacon. They "shed greatest light and carry great authority" (ibid., p. 321).

[86] Ibid., pp. 319–321. Although Bacon formulates his examples by giving two alternatives to choose from, it is clear from the development of those examples that the two alternatives are not exclusive and that there may be more than two theories at stake.

Instances on the matter."[87] Bacon himself suggests that crucial instances can play different roles: some might be called "Decisive and Judiciary," while, "in some cases, [they are called] Instances of Oracle and Instruction."[88] This difference in terminology suggests a difference in function: in some cases, crucial instances can help the intellect decide definitively (as to which direction to go); in some other cases, they point to questions, puzzles, further problems, etc.[89] My suggestion is that reading the whole theory of crucial instances solely in terms of evidence, although not entirely wrong, is slightly misleading.[90] Crucial instances are (mostly) experiments; and, as all Baconian experiments, they are open ended, productive, and can be developed into a series of experiments and results. They can be used to generate whole natural histories.[91] In some cases, they are useful because by refuting or questioning accepted theories, they free the mind to inquire further. In other cases, they offer examples of how things can be otherwise than in the received theories, without offering, at the same time, a positive confirmation of a particular theory. Here is one example: Bacon's discussion of the nature of the moon. According to the theories available, the moon was either a solid body (as Gilbert has stated) or a fiery one (as Bacon's theory of matter states sometimes). The main argument of the "Moon is a solid body" camp was that since the surface of the moon reflects the rays of the sun, the moon cannot be a fiery body. A Crucial Instance, therefore, would be an experiment showing that one can have reflection of light on a fiery body. Bacon gave two such instances: the reflection of light on the luminous clouds, at sunrise or sunsets, and an actual experiment involving the reflection of a more powerful light on a less luminous flame:

> We should perform an experiment of letting the Sun's rays shine from a hole over any smoky or bluish flame. For indeed the Sun's free rays falling on darker flames seems as it were to neutralize them so that they look more like white fumes than flames.[92]

In what way is this a crucial instance? Showing that reflection is possible on a flame refutes the major argument of the contending theory, but does not prove that the moon is made of fiery substance. At best, it opens a new line of experimentation into the nature of tangible and fiery matter and their respective properties. Therefore,

[87] Ibid., pp. 327, 331.
[88] Ibid., p. 319.
[89] Such questions, puzzles, etc. are, presumably, responses to a puzzling oracular instance.
[90] For such a reading, see Urbach (1987).
[91] In fact, the examples formulated by Bacon in the theory of crucial instances have all been used to develop natural histories either by himself or by his followers in the early Royal Society.
[92] *OFB*, vol. 11, p. 333.

crucial experiments function both as evidence and (probably more importantly) as core experiments from where new natural histories can be generated.

This is also the way in which Robert Boyle and Robert Hooke read Bacon's theory of crucial instances. For example, in his natural history of colors, Boyle appealed something like Bacon's theory of crucial instances in order to refute some of the six competing alternative hypotheses on the nature of light.[93] As for Hooke, as it has shown before, he coined the term *experimentum crucis*, starting from his own creative reading of Bacon. It is highly relevant, I think, that Hooke's experimentum crucis appears within a "natural historical account,"[94] in the context of successive strings of Baconian experimentation regarding the production of colors in very thin plates. After establishing that the production of colors does not depend on the material of the plate or on the nature and quality of the light source, but only on the thinness of the plate, Hooke claimed that, incidentally, Descartes' theory about the production of colors is refuted. As a result:

> This experiment therefore will prove such a one as our thrice excellent Verulam calls Experimentum Crucis, serving as a Guide or Land-mark, by which to direct our course in the search after the true cause of Colours. Affording us this particular negative information that for the production of Colours there is not necessary either a great refraction, as in Prisme; nor Secondly, a determination of Light and shadow, such as is both in the Prisme and Glass-ball.[95]

"This experiment" refers to the whole string of experiments performed so far. They offer, in Hooke's view, "negative information," and, in consequence, can be used to refute Descartes' theory of colors. In this sense, the crucial experiment functions as a Baconian Crucial Instance, as "a guide or land-mark." But the crucial experiment is not used to confirm a theory. In fact, again, the position of Hooke's crucial experiment in the argumentative structure of Observation IX of *Micrographia* is extremely important. It comes as a conclusion of a "historical" part and just before Hooke formulates his own hypothesis on the nature of light. It also plays the role of a turning point in the demonstration. Hooke claims:

> Now that we may see likewise what affirmative and positive Instruction it yields, it will be necessary to examine it a little more particularly and strictly;

93 Boyle (1664).

94 Observation IX of *Micrographia*; see also section 2 of this paper.

95 Hooke (1665, p. 54).

> which we may the better do, it will be requisite to premise somewhat in general concerning the nature of Light and Refraction.[96]

After formulating his own hypothesis on light, Hooke offers a new series of experiments (refraction on thin plates and "Balls of water," and prisms) destined to refute the Cartesian theory. They are all versions of the same experiment of refraction, obtained through experimental variations of relevant parameters. And they are also said to "afford" an "Instancia crucis":

> For is does very plainly and positively distinguish, and shew, which of the two Hypotheses, either the Cartesian or this is to be followed, by affording a generation of all the colors in the Rainbow, where according to Cartesian Principles there should be none at all generated. And secondly, by affording an instance that does more closely confine the cause of these Phenomena of colours to this present Hypothesis.[97]

It is clear that Hooke uses the crucial experiment in Bacon's sense, as a guide in the investigative procedure; a crucial experiment can be used to refute a particular hypothesis and give some support to another. It does not, however, confirm a hypothesis and it does not transform a hypothesis into an established truth.

It is not surprising, therefore, that when reading Newton's paper, Hooke acknowledges the "ingenious character" of the crucial experiment, but also asks the question regarding the theory that this experiment supposedly refutes. He points out that the Newton experiment does not refute his own hypothesis (in the same way in which his crucial experiments refuted Descartes' theory).[98] In the course of their subsequent correspondence and debate, Hooke emphasizes more than once that Newton has a mistaken understanding of "crucial instance" and "crucial experiment," and, hence, that his paper gives a distorted and illegitimate reading of the term. In fact, Hooke's first objections to Newton's paper are easy to understand if read from the perspective of Baconian natural history, as I have tried to reconstruct here. They fall into three categories: first, Hooke raises objections against some of Newton's experimental results and suggests improvements or alternative experiments. This is a perfectly legitimate reaction in natural historical research (it is, in fact, the reaction expected from a serious

[96] Hooke (1665, p. 59).

[97] Ibid.

[98] Following Bechler, I suggest that Hooke did not reject Newton's hypothesis, but regarded it as a "very ingenious" and fair competitor; hence, he was willing to take it into consideration and to imagine further experiments to test and improve it. This was also Huygens' initial reaction. See Bechler (1974).

reader). Second, Hooke signals two more serious philosophical problems: that Newton used his own term, *experimentum crucis*, in an illegitimate way, and that he claims a degree of certainty for his demonstrations, which is highly problematic in natural history.

2.7 CONCLUSION

My aim in this paper was to show that a good number of traditional difficulties in reading Newton's first paper on light and colors disappear if one reads it in the key of the genre to which it properly belongs, namely Baconian natural history. Using recent developments in the scholarship, I have offered a historical and philosophical reconstruction of Francis Bacon's natural historical project, outlining some of its important elements. I have shown that Newton's first paper displays such elements of natural history both in its structure, (formal) composition, and its experimental content. As recommended by Bacon, Newton constructed his experimental research in a series of experiments generated from one another by controlled variation of parameters. Like Bacon, Newton attempted to present all his results as experimental results, "facts" constructed directly from experiment. This allowed him to give a special status to his main result, i.e., the different degrees of refrangibility. Meanwhile, in taking Hooke's phrase, "crucial experiment" and giving it a new meaning, Newton extended too far a step that was otherwise standardly used in critical reflection on the powers and advantages of natural history, giving it a dogmatic twist of which neither Bacon, nor Hooke could have approved.

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