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Unveiling the Diversity of Enlightenment Experimentation: Insights from Charles Bonnet's Naturalist Practices

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Abstract This article critically examines Charles Bonnet's seminal contributions to experimental science, particularly through his influential work, 'Research on the Use of Leaves.' The primary objective is to delineate the functions and forms of natural experimentation as they were understood and practiced in the mid-18th century. During this period, scientists esteemed experimentation as the zenith of scientific proof, acutely cognizant of its multifaceted functional and typological aspects. Their methodology was characterized by a detailed narration of research methodologies, fostering a 'rhetoric of transparency' in scientific discourse. Nevertheless, the advent of new norms in scientific discourse during the 19th century, coupled with a paradigmatic philosophical shift in the 20th century, resulted in the marginalization of empirical practices of the Enlightenment era. Contemporary historians are now endeavoring to reconcile significant terminological discrepancies and to recontextualize the divergent methodologies among natural historians of that epoch. This involves a critical distinction between exploratory and demonstrative (or discriminant) forms of experimentation. Bonnet's systematic preference for discriminant experimentation serves as a quintessential example of the logical approach in natural history. However, this perspective does not wholly represent the 18th-century 'art of observation,' which embraced a plethora of methodologies including taxonomy, anatomical dissection, chemical analysis, and physical measurements.

Index Terms Charles Bonnet, natural experimentation, typology, 18th century.

I. Summary

This article aims to characterize the functions and forms of naturalist experimentation during the mid-18th century, drawing inspiration from Charles Bonnet's seminal work, "Research on the Use of Leaves." It reveals that Enlightenment scientists, perceiving experimentation as the pinnacle of scientific demonstration, possessed a keen awareness of its diverse functional and typological aspects. This awareness was accentuated through detailed narrations of their operations, creating a "rhetoric of transparency." The subsequent dominance of a "Laplacian" standard in the 19th century and a philosophical shift in the 20th century resulted in the oversight of the richness of Enlightenment empirical practices. Nevertheless, contemporary historians are rediscovering, despite terminological differences, the significant divisions established by 18th-century scholars. These divisions notably distinguish between exploratory observation and demonstrative (or discriminant) experimentation. Charles Bonnet's penchant for discriminant experiments exemplifies a style of research termed "logician naturalism." However, this characterization does not fully capture the multifaceted "art of observing" in the Enlightenment, extending to taxonomy, anatomical dissection, chemical analysis, and physical measurement.

The notion that scientific experience serves various functions is not inherently obvious. In a historical context influenced by philosophers like Popper or Reichenbach, there existed a prevailing "classic" perspective wherein experimentation primarily validated theories, hypotheses, or mathematical laws1. Recent scholars, such as [1], have significantly nuanced this view, revealing intricate connections between theory, hypotheses, informal knowledge, instrumentation, technical expertise, and practical execution of experiments [2]. Historians like [3], [4] recognized two distinct types of experiences- "exploratory" and "theory-driven"-in the practices of researchers like [5], [6] noted that 19th and 20th-century physicists often overlooked the exploratory aspects of their investigations to align with the prevailing norm of scientific research [4]. Consequently, historians must reconstruct the authentic logic of effective scientific practice by delving into laboratory notebooks and unveiling the existence of exploratory experiments, crucial for opening new fields, developing concepts, and forming classification schemes.

In the context of 18th-century natural history, exploratory experimentation wasn't concealed but rather served as a legitimizing force for empirical practices, challenging speculative approaches linked to long-standing mechanistic dominance6. A previous study on Bonnet emphasized the role of experimentation, whether discriminating, analytical, or exploratory, as an integral part of the rhetoric of scientific [7]. During the mid-18th century, this rhetoric of transparency elevated

the meticulous description of approaches, experiments, and precautions as central elements of scientific demonstration and [8]. Far from being seen as a threat to scientific rigor, the narration of exploratory experiences, even those that were unsuccessful, emerged as a means of showcasing the observer's good faith and absence of theoretical biases. Building on the sincerity of Enlightenment scholars, we aim to delve deeper into the typology of experimental practices, a topic that has received limited attention from historians of science, despite some exceptions [9].

II. Formal Distinction Between Observations and Experiments

Charles Bonnet initially referred to his concrete operations as "observations," reserving the term "experiments" for later use in his [10]. Although the reasons for this terminological difference remain unexplained, insights from Bonnet's disciple Jean Senebier shed light on the matter. In [11] contrasted the passive and "natural" nature of observation with the active and "artificial" character of experience. According to him, observation entails a focused and thoughtful examination of Nature through the senses to acquire precise knowledge of its qualities, causes, or effects. Conversely, experience involves studying the objects of Nature by subjecting them to tests designed to penetrate their mysteries. The result instructs the soul by acting on it through the senses. Therefore, knowledge acquired through observation is that of Nature itself, while knowledge obtained through experience is limited to an attempt to probe Nature, distinguishing between the observer perceiving Nature and the experimenter seeking means to perceive it.

In essence, three distinct levels of interaction with nature can be discerned, as outlined by Jean Senebier:

Natural Observations: This involves observing phenomena directly or using magnifying tools to study them in their natural state.

Induced Observations: Conducting observations under controlled conditions, often involving specialized devices like microscopes or in vitro setups. These observations are intentionally induced to study specific aspects of nature.

Experiments

This level involves actively modifying parameters of reality, such as organ sectioning, to understand the cause-and-effect relationships within nature. The experimenter, according to Senebier, engages in a regulated conversation with nature, bearing the responsibility and costs associated with the experiment. Senebier emphasizes that experimenters must employ "unwelcome violence" to force phenomena to reveal their secrets. They must pose questions, remain attentive to answers, and leverage observations to illuminate further inquiries. Moreover, he contends that artificial experiments should be validated by observations in a natural setting, highlighting the significance of grounding laboratory findings in the broader context of nature.

Charles Bonnet's approach, while not explicitly addressing the epistemological status of artificial operations, reflects a diverse range of empirical investigations. Bonnet's work extends beyond what Max Grober characterizes as "provoked observations," encompassing genuine experiments where he actively modifies parameters in his study on leaf utilization. Despite Senebier's focus on chemical experiences, Bonnet's empirical investigations primarily involve logical discrimination between causal factors, with a reluctance toward extensive chemical analysis or precise physical measurements.

In summary, Charles Bonnet's scientific methodology embodies a nuanced blend of observation and experimentation, where the boundaries between these practices are not rigidly defined. His work showcases a logical and multifaceted approach to comprehending the complexities of the natural world during the 18th century.

III. A Functional Distinction: Analytical Observation and Demonstrative Experience

Two distinct categories emerge in the context of Bonnet's work on the use of leaves: analytical observation and demonstrative experimentation. This categorization, articulated by Albrecht von Haller or Samuel Formey, provides a functional distinction rather than a strictly formal one, aligning closely with Bonnet's implicit methodology. The two types of observations or experiments are as follows:

Analytical Tests

These are designed to collect and establish facts, contributing to both the constitution of the objects of study and the establishment of phenomenal typologies. Analytical tests serve both exploratory and generalizing functions, playing a role in the formulation of hypotheses and the study of their extension, variations, and temporal development. These may include exploratory observations, provoked observations, or real experiments, and they align with the concept of "exploratory experiments" in modern historiography.

Demonstrative Tests

The primary goal of demonstrative experiments is to validate or refute hypotheses, study relationships between facts, or highlight the existence of a phenomenon. These experiments are often discriminative in nature, involving the isolation of variables or structural components through procedures such as sequestration or fragmentation. Demonstrative tests correspond to what modern historians term "theory-directed experiments."

While these distinctions are not explicitly articulated in Bonnet's writings, they reflect the functional diversity inherent in his investigative practices. Analytical experiences often precede demonstrative ones, with the former involved in the constitution of facts and the latter in the formulation and validation of hypotheses. However, the chronological sequence is not rigid, as investigations may commence with a hypothesis formulated based on exploratory observations.

Bonnet employs two research tactics based on the complexity of the questions at hand. For relatively straightforward questions, such as etiolation or the degeneration of wheat into tares, he often resorts to demonstrative experiments that yield clear results. However, for more intricate topics, like the nutrition of plants through their leaves, the implementation of crucial experiments is challenging. In such cases, Bonnet opts for exploratory and generalizing experiments, along with non-decisive discriminative experiments, resulting in provisional or uncertain outcomes.

IV. Analytical Procedures in Scientific Inquiry: Gathering and Characterizing "Facts" or Exploring and Generalizing

The role of analytical procedures in Bonnet's research is crucial, involving the collection, characterization, exploration, and generalization of facts. The investigative tactics often lead to a perceived "accumulation of facts," especially when addressing complex subjects. The choice of facts to study is purposeful, guided by their significance and implications for understanding the functions of leaves. The impression of accumulation stems from the intricate nature of the subjects, with Bonnet's investigations serving as an inventory and description of various phenomena and variants. The exploratory mode, driven by questions formulated through observation, also plays a substantial role, particularly in the study of complex phenomena.

V. Analytical Procedures Inventory: Exploratory Experiments, Generalizing Experiments, and Descriptive Sequences

In the pursuit of understanding leaf phenomena, Charles Bonnet conducted experiments to unravel the mystery of leaf reversal. Placing "jets" of twenty different herbaceous and woody species in positions contrary to their natural alignment, he observed their consistent return to the original direction, pinpointing the phenomenon's locus at the pedicle (Figure 1). To ascertain the extent of this reversal, he repeated the process fourteen times, each time resulting in a return to the initial position.

Beyond cataloging phenomenological "forms" and analyzing them from a generalizing perspective, Bonnet delved into studying processes unfolding over time. For instance, in investigating sap circulation, particularly the identification of operational channels, he rejected simplistic conclusions drawn from colored infusions accumulating in woody fibers. Recognizing the need for a temporal analysis, he crafted a descriptive experimental sequence. Immersing plants in dye through their roots, he performed sequential dissections at intervals, revealing the color's progression from wood fibers to bark fibers. Communication between these networks emerged as a complex puzzle, solved through a convergence of clues.

Another descriptive sequence aimed to showcase sap circulation involved continuous observations using a glass tube containing mercury attached to a branch section. Bonnet envisioned unveiling the diurnal rise and nocturnal descent of sap, even attempting to measure sap strength by mercury elevation for cross-subject comparisons. While this experiment remained a project due to its challenging execution, it played a crucial role as a thought experiment in Bonnet's rhetorical strategy Figure 2.

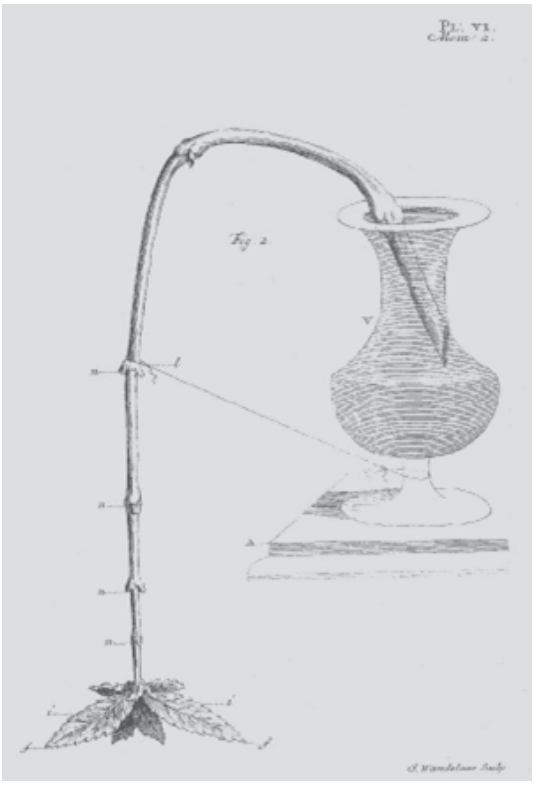

Figure 1: Illustration of a restraining procedure. A stem of Mercurial has its upper end brought down and held in this position by a wire attached to the foot of the vase, so that the lower surface i, i of the leaves looks at the sky. The end of the rod thus placed soon turned towards the sky, the nodes n, n serving as the main points of inflection.

A. Analytical procedures	
- Proceduresexploratory	Identification of new phenomena, or "facts", or inventory of "forms" and their modalities
- Proceduresgeneralizing	Study of the generality and limits of a phenomenon, or analysis of its extension
- Sequencesdescriptive	Analysis of a process by of the sequels observations staggered In THEtime
- Variations	Modifications of experimental protocols (by inversion, parameter modification, etc.)in order to "test" a fact, its limits or its variants
- "Fishingline"	Random investigation, without a specific plan, in the hope of seeing something unexpected emerge
B. Proceduresnon-discriminatory demonstratives	
- Experiences inmirror	Reversal of an experimental process to demonstrate the validity of an explanation
- Artificial experiments	Creation of functioning models intended to reproduce the characteristics of a natural being
- Practical applications	Testing a fact or discovery through an efficient technical process
C. Discriminatory procedures	
- Sequestration	Isolation of an organism byrelationship to the surrounding environment
- Simple shutter	Interruption of any exchange of substances between an organism and its environment
- Differentiated shuttering	Interruptionselective exchange of substances between an organism and its environment
- Fragmentation	Division of an organism into several parts in order to study the relationships between these parts,as well as the nature of the whole
- Separation	Removal of an organ or part for study separately from the whole
- Removal	Removal of an organ or part in order to study its function in the whole
- Sectioning	Interruption of the relationship between two parts of an organism or a whole
- Obstruction	Discomfort to the free exercise of an organic function

Figure 2: Attempt to inventory the forms of experimentation implemented by Bonnet in his Research on the use of leaves.

VI. Exploring Analytical Tests: A Profound Inventory

The exploration of analytical tests in Charles Bonnet's work can be enriched by delving into Gabriel Cramer's

"Logic Course," a foundational influence alongside Jean-Louis Carandini during Bonnet's tenure at the Academy of Geneva. Cramer's teachings, preserved in a copy owned by Bonnet himself, provide valuable insights into methodological approaches employed by several generations of Genevan scholars.

Cramer's text delineates eight means of inventing and conducting new experiments or verifying existing ones. Notably, these means encompass variation, extension, inversion, conjugation, application to useful objects, random improvisation, and the artistic reproduction of natural phenomena-exemplified by Bonnet's creation of artificial leaves. The multifaceted nature of these methods, coupled with the emphasis on experiment repetition and variation, sheds light on the extensive experimental sequences presented in Research on the use of leaves.

Bonnet occasionally embraces chance by undertaking "blind" experiments without preconceived questions-a practice not uncommon in scientific exploration. This nuanced approach to experimentation, deeply rooted in the teachings of mentors like Cramer, contributes to the intricate tapestry of Bonnet's empirical inquiries. in the 18th century, which Claude Bernard will describe as "angling" 40. But overall, the Geneva scholar is not in favor of a multiplication of operations of this kind. On the contrary, throughout his work, he will increasingly insist on the need to frame experiences through a true process of analytical reflection, which makes it possible to define more discriminating protocols and to give meaning. more accurate to experimental results.

VII. Demonstrative and Discriminative Procedures: Towards a Typology

In delineating the various forms of investigation employed by Charles Bonnet, a notable category emerges-non-discriminatory demonstrative procedures. Within this realm, mirror experiments, the crafting of artificial models, and the practical applications of experimental findings occupy a distinct space, marked by their non-crucial nature in the administration.

Despite these non-discriminatory approaches, Bonnet consistently leans towards discriminating and preferably crucial experiments, a hallmark of his experimental methodology. Two primary types of discriminating procedures, as elucidated by Marino Buscaglia in the context of the Treatise on Insectology, include sequestration and fragmentation. Expanding on these, Research on the use of leaves introduces numerous variants, characterized as procedures involving obturation (simple or differential), separation, ablation, sectioning, or obstruction.

The sequestration procedure, isolating an organism for controlled examination, draws inspiration from historical models such as Redi's protocols for studying spontaneous generation and Mayow's approach to establishing animal respiration (specifically, confining individuals under glass bell jars). In the realm of plant physiology, sequestration primarily pertains to understanding environmental relationships, as the isolation of individual plants may lack significance in this context. Hales had previously employed sequestration in his investigations, particularly focusing on plant responses to environmental stimuli. This methodology, evident in Hales' work, laid a foundation for Bonnet's experimental style and its distinctive reliance on discriminating experiments, contributing to the rigor of his scientific approach.

In the realm of experimental variation, Bonnet delves into differential filling to unravel the intricacies of leaf functions. Notably, he probes into the potential role of stomata in transpiration, employing a technique where the upper or lower leaf surfaces are selectively oiled. By meticulously measuring water absorption under varied conditions across numerous plant species, he endeavors to substantiate his hypothesis. Despite the experiment's complexity and the diversity of outcomes, Bonnet successfully demonstrates a general trend-greater absorption when the upper leaf surface is treated. This nuanced approach illustrates the importance of considering specific factors and selective interventions in experiments, a practice that aligns with Bonnet's commitment to discriminating investigations.

In navigating the diverse landscape of discriminating procedures, Bonnet's contributions extend beyond sequestration and differential filling. From exposing vine leaves to sunlight under controlled conditions to intricate investigations involving oil treatments, his experimental repertoire mirrors a dynamic engagement with the complexities of plant physiology. Each nuanced approach, rooted in logical discrimination, contributes to Bonnet's broader mission of unraveling the intricacies of natural phenomena. the leaf during its development and growth, Bonnet aims to unravel the role played by different components. His approach involves removing various elements such as the petiole, stipules, or even sections of the lamina. Through this methodical process, Bonnet seeks to discern the impact of each ablation on the overall functionality of the leaf. This discriminating procedure aligns with his commitment to dissecting complex structures to uncover the specific functions of individual parts.

Bonnet's nuanced use of ablation reflects a meticulous and inquisitive approach to understanding plant physiology. Rather than resorting to a blanket dissection, he carefully selects specific elements for removal, recognizing the potential influence of each component on the observed phenomena. This discriminating approach allows him to probe deeper into the intricacies of leaf development and function, highlighting the interconnected nature of botanical phenomena.

VIII. Conditions of appeal to experimentation according to Bonnet

Bonnet employs various discriminating procedures in his exploration of plant physiology. A significant one is the sequestration procedure, isolating organisms to examine them in controlled environments. While historical models, such as those by Redi and Mayowa, influenced this approach, Bonnet's variations, like exposing a vine leaf to sunlight under a bell, demonstrate a nuanced application. Another procedure

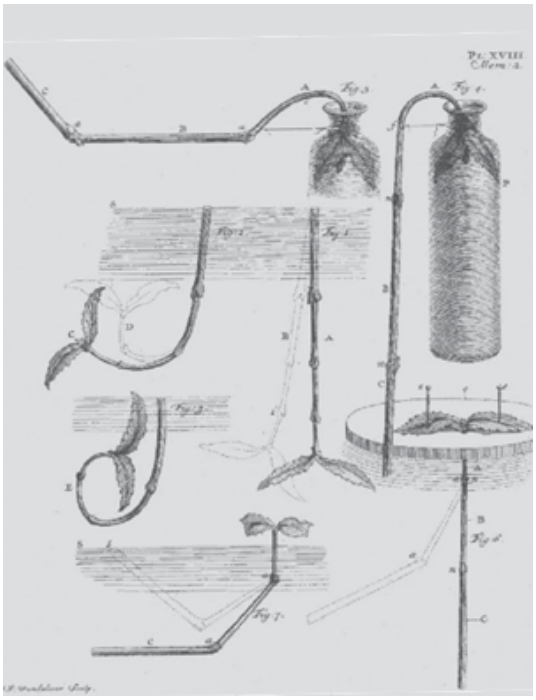

Figure 3: Plate illustrating different restraining procedures imagined by Bonnet to study the turning of leaves (IIeMemory, pl. XVIII).

involves obstructing substance exchanges between an organism and its environment, such as plunging branches into oil to investigate the role of "tracheas." Bonnet also employs a differential filling method, selectively blocking openings to study substance exchanges more selectively, Figure 3.

Moreover, Bonnet relies on fragmentation, dissecting organisms into parts, and separation, detaching parts to analyze properties independently. In cases like the study of leaf surfaces' absorption abilities, he often opts for separation, using detached leaves to simplify protocols. Ablation involves removing parts, as seen in the investigation of cotyledons' role in plant growth. Severing interrupts communication between two parts, as seen in experiments on bean plants.

Lastly, the obstruction procedure involves hindering a function's free exercise to demonstrate its existence or understand its nature. This could include unconventional positioning of stems or physically hindering leaf movements. Overall, Bonnet's discriminating procedures, while rooted in historical methods, exhibit unique variations that align with his botanical explorations. Bonnet, while cautious about causing undue suffering to animals, did engage in animal experiments using knives and probes. His reluctance towards violent experiments did not hinder him from conducting intensive operations on worms, hydra, snails, and salamanders, with repeated procedures to establish reasonable certainty.

Practical considerations defined the real limits of experimentation for Bonnet. Attention to experimental circumstances, avoidance of errors, identical test repetitions, and varied protocols were precautions he considered vital. He recognized the importance of these precautions, especially when dealing with significant theoretical questions, such as the non-degeneration of wheat into tares. The tedious protocols, combining sequestration devices and executed multiple times, aimed to provide more decisive and convincing results. Bonnet's adherence to a probabilistic conception of knowledge demanded patience and tenacity from experimenters, qualities celebrated in contrast to the conceit of "system makers." The challenge lay in articulating hypotheses with their implementation and interpreting results theoretically, a methodological difficulty Bonnet sought to address amid the significant expansion of his theoretical horizon.

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