Jean Senebier's thoughts on experimentation
and their relevance for today's researcher

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Abstract
How are observation and experimentation related to one another? Jean Senebier (1742-1809) tackled this question in his philosophical works on The Art of Observing. However, Senebier was not only a theoretician and, not long after his first publications on observation, his own experiments contributed to resolve a major question in biology: what do the leaves of plants feed on? By analysing Senebier's works on science theory in parallel with those reporting his scientific discoveries, this article shows that The Art of Observing series is not restricted to observation and contains deep insights into the process of experimenting with living organisms.

Keywords: *Senebier, plant physiology, photosynthesis, science didactics, epistemology*

Résumé
Les considérations de Jean Senebier sur l'expérimentation et leur intérêt pour les chercheurs d'aujourd'hui. – *Quel est le lien entre l'observation et l'expérimentation? Jean Senebier (1742-1809) a abordé cette question dans sa série d'ouvrages sur l'Art d'observer. Cependant, Senebier n'était pas seulement un théoricien et, peu après ses premières publications sur l'observation, il a commencé à travailler sur l'une des grandes questions de la biologie: «de quoi se nourrissent les feuilles des plantes?» S'appuyant sur ce qu'il avait appris en tant qu'expérimentaliste, Senebier a par la suite été en mesure d'approfondir ses brillantes analyses présentées dans ses deux premières publications sur l'Art d'observer. La série entière nous renseigne non seulement sur l'observation, mais contient également une analyse approfondie sur les avantages, les limites et les difficultés inhérents à toute expérience scientifique effectuée avec des organismes vivants.*

Mots-clefs: *Senebier, physiologie végétale, photosynthèse, didactique des sciences, épistémologie*

Introduction

Jean Senebier involved himself in many fields of activity and wrote on subjects as diverse as polygamy, religion, soap manufacture and meteorology. There were, however, two subjects that held his attention over a long period. Each of these would lead to a series of three major works and each has easily withstood the test of time. The first is *The Art of Observing* series published between 1772 and 1802[1]. This is Senebier's classic work on science theory and, consistent with the title, is largely dedicated to how to make scientific observation. Interestingly, readers of this work have pointed out that the last (1802) version marked a change in Senebier's thinking since this book contains a volume devoted exclusively to experimentation rather than to observation alone[2]. The second important series of works produced by Senebier describes his own painstaking experiments leading to one of the major discoveries in biology: that leaves 'feed on' inorganic carbon. This discovery, one of the foundations of photosynthesis, was published in the period from 1772 to 1788, that is, in the 'middle' of the *Art of Observing* series[3].

1 Senebier 1772, 1775, 1802.
2 Grmek 1991.
3 Senebier 1782, 1783, 1788.

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The present article investigates the interrelationship of the two sets of works. Specifically, and given that Senebier himself was an accomplished experimentalist, it is relevant to re-examine how *The Art of Observing* series might have been influenced by Senebier's own research. Did Senebier's experiments impact what he wrote in *The Art of Observing*? If so, how? What if any gems does the work contain concerning experimental method? And what sort of language did Senebier use to treat this difficult subject? These are the questions addressed herein. The answers to these questions remind us clearly that we need to understand both the limits and the power of experimentation at least as well as our predecessors did. But it is first necessary to elaborate on what Senebier discovered and then examine how the discovery was made.

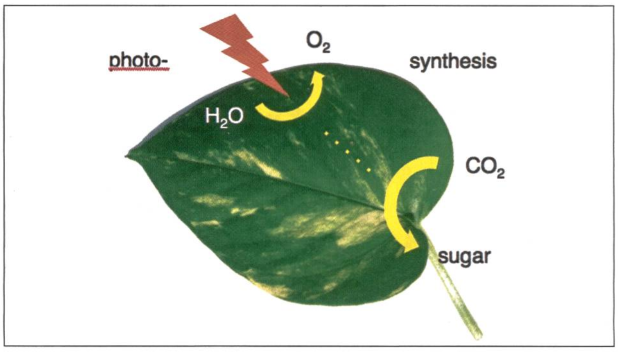

Fig. 1. Photosynthesis. In the 'photo' part of photosynthesis leaves use light (orange strike) to split water to release oxygen and to produce energy. The energy is transferred (dashed line) to the 'synthesis' part of the process to help fix carbon dioxide into sugars. Jan Ingenhousz can be seen as initiating work on the 'photo' part by discovering that leaves released oxygen in the light. In contrast, Senebier discovered that leaves take up carbon dioxide thus initiating work on the 'synthesis' part of photosynthesis. At the time of their discoveries oxygen (O_2) and carbon dioxide (CO_2) equated to 'air pur' and 'air fixe' respectively. The role of water (H_2O) and the fact that sugars are made from CO_2 were discovered later.

Senebier's discovery

The uptake of carbon by the leaves of plants was discovered by Jean Senebier. This is arguably the most important process in the biosphere since, having captured carbon, photosynthetic organisms form the basis of the food chain. Previously, another Genevan, Charles Bonnet (1720-1793), had shown that leaves placed in water released bubbles of gas[4]. Only later would these bubbles be known as 'air pur', and subsequently as the oxygen produced by photosynthesis (shown in fig. 1). Jean Senebier, greatly influenced by Bonnet, used a similar experimental system (leaves submerged in water) but turned the problem on its head asking what leaves take up from the water in order to release easily visible bubbles of gas. Many years later when he summarised this work in his encylopedia *Physiologie Végétale* Senebier entitled one section as *'Carbon dioxide considered as a food for plants'*[5]. There is no better way to say this today.

The two major works summarizing Senebier's discovery, *Mémoires Physico-chimiques* and *Recherches* appeared after Jan Ingenhousz's book *Experiments on Vegetables* in which Ingenhousz, also strongly influenced by Bonnet, demonstrated the need for sunlight to promote the release of oxygen from leaves submerged in water[6]. While the importance of Senebier's discovery of carbon uptake is clear and important to us today it was also cherished by Senebier himself. Indeed, it is surely not accidental that he placed the description of this process at the epicentre of the five volume *Physiologie Végétale*, in the very heart of the central volume[7].

Senebier's contribution is notable for several reasons. Firstly, the work showed the principal function of leaves: to capture carbon for food and what leaves did for a plant had been a mystery even to Bonnet. Secondly, carbon capture by plants provides food for other organisms. Closely related to this, carbon fixation on a global scale is a reversible process in that decaying plants and animals return most of their carbon to the atmosphere. By combining his work with the concepts of Priestley, Lavoisier and others, Senebier would write in *Physiologie Végétale*

> Dead plants depose into the ground their debris which form the largest part of the fertiliser through their fermentation. In this way they render to the soil and to the air what they have taken[8].

This is an early appreciation of the 'carbon cycle'. A third aspect, and one which is more relevant to the present article, is that the discovery of carbon uptake by leaves must have been very difficult to accomplish for technical reasons and also because of the infancy of modern chemistry and physiology.

4 Bonnet 1754.
5 «Du gaz acide carbonique considéré comme un aliment des végétaux»; Senebier 1800, vol. 3, p. 148.
6 Senebier 1782, 1783; Ingenhousz 1779.
7 Senebier 1800.
8 «Les végétaux morts déposent encore dans la terre leurs débris qui forment la plus grande partie des engrais par la fermentation qu'ils éprouvent, & ils rendent ainsi à la terre & à l'air ce qu'ils lui ont pris»; Senebier 1800 vol. 3, pp. 164-165.

Ingenhousz had stated that:

> It is an unfortunate circumstance that air is not an object of our sight[9].

But at least bubbles of gas could be seen emerging from leaves in water (as had been described by Bonnet). This was not the case for a colourless, low abundance substance taken up by leaves. Then there was the fact that carbon dioxide and carbonates had not been fully defined chemically. And finally, although Senebier avidly followed new developments in pneumochemistry, the field in the 1780s had still not shaken off the erroneous and misleading theory of 'phlogiston'[10]. Inspite of all these difficulties Senebier applied a precocious knowledge of scientific method to a difficult problem and succeeded in making a discovery of fundamental importance[11]. Now, from today's perspective, it's clear that Senebier's place among other pioneers of photosynthesis (shown in fig. 2) is primordial, since all life on Earth is carbon-based. Senebier's discovery paved the way to understanding how inorganic carbon was incorporated into organic matter in the living world.

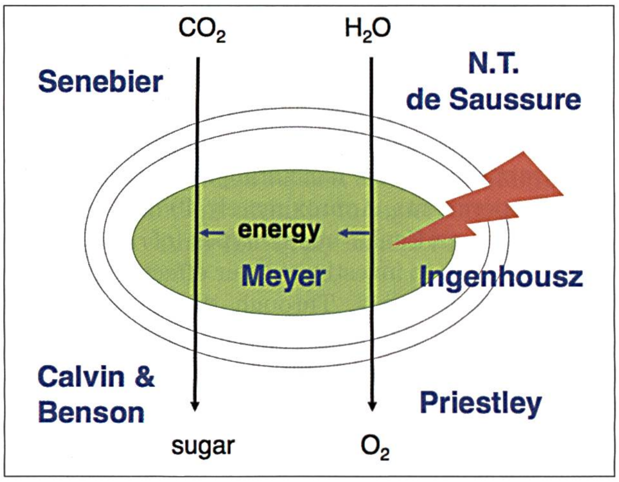

Fig. 2. Senebier's place among the discoverers of photosynthesis. The concentric circles represent the outer membranes surrounding chloroplasts, the chlorophyll-containing organelles in plant cells in which photosynthesis occurs. Each leaf typically contains tens of thousands of chloroplasts present in multiple copies in most of the cells. Green represents the innermost chlorophyll-containing membranes which capture light energy. The place occupied by seven of the major discoverers of various aspects of photosynthesis is indicated. Note that both N.T. de Saussure and Senebier worked in the Geneva region. Strictly speaking Senebier discovered carbon uptake (also referred to as 'capture' or 'consumption' in this article) but not carbon 'fixation' the mechanism of which was revealed much later by Calvin and Benson. The figure was inspired by Rabinowitch (1971).

Senebier the experimentalist

Trying to understand what leaves procured from the water in which they were immersed demanded more than observation: experiments were needed. Here it was to be Senebier's interest in chemistry and his willingness to experiment with chemicals that provided a key to his success. This is evident in his *Mémoires Physico-chimiques* (1782), even more so in his *Recherches* (1783), and also in a third book published five years later[12]. The 1783 book bestowed praise on prominent chemists with Senebier stating:

> ...the chemistry of Scheele, of Bergman, of Lavoisier, of Priestley, is that sublime science and every naturalist would be happy to know of such a science and of such scientists[13].

More interestingly, reading this book illustrates that Senebier's own way of doing experiments had helped to open a new way of investigating a living system (the leaf) by subjecting it to chemical treatments. Senebier's approach equated to something one might term 'chemical physiology.'

Over time, and in order to measure the quantity of gas released by leaves Senebier employed glass vessels of various kinds. Perhaps the most useful of these vessels resembled an inverted funnel with a closed and graduated neck (fig. 3). For each experiment, healthy leaves freshly cut at the base of their petioles were placed in the vessel full of water which was then immersed in a bigger bath of water so that all air bubbles could be eliminated. Then a saucer-like base could be placed over the funnel. The apparatus would then have been lifted out of the water bath and inverted as shown in fig. 3. Finally, the saucer was filled with water and the vessel was then exposed to sunlight. As time passed the leaf released gas and the amount produced could be read from the graduations in the neck of the apparatus.

Using this type of container Senebier then systematically tested a number of variables to estimate their influence on oxygen production by leaves. For example, he treated the water by boiling it or by adding acids or alkalis, etc. He also explored the effects of different volumes of water by using vessels of different sizes. Yet another variable was the type of leaf

[9] Ingenhousz 1779, p. 34.
[10] Legée 1991.
[11] Bay 1931; Rabinowitch 1971.
[12] Senebier 1782, 1783, 1788.
[13] «...la Chymie de Scheele, de Bergman, de Lavoisier, de Priestley est cette science sublime, & chaque Naturaliste sera charmé de savoir qu'il y a une telle science & de tels Savants»; Senebier 1783, p. IX.

used and the leaves from plants as diverse as pine and snowdrop were tested. It seems that Senebier's favorite leaves were from peach (*Prunus persica*) trees. Peach leaves, he found, were resistant to many chemical treatments and the thin blades contained little trapped air, thus facilitating the interpretation of the experiments. Approximately 40 different substances (in particular many types of acid) were added to water to investigate their effects on oxygen production by leaves. Through this tireless work Senebier found that acids acting on carbonates in water facilitated oxygen production by leaves but, importantly, too much strong acid would kill the leaf. Nevertheless, he was able to piece together a coherent picture of the conditions necessary for carbon uptake by living leaves in water.

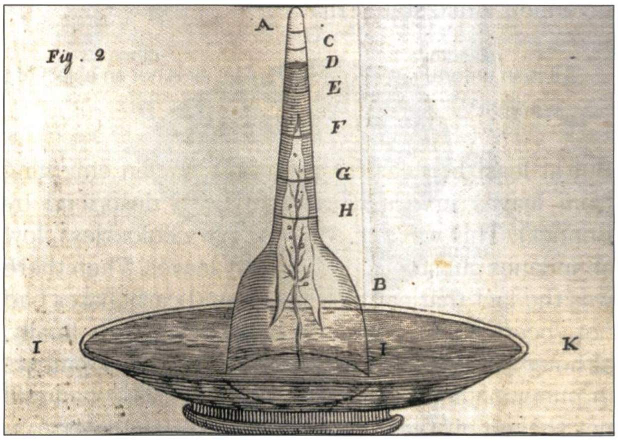

Fig. 3. One of the glass vessels used by Senebier to estimate the volume of gas produced by a leaf submerged in water[34]. *The leaf represented in this figure might be from sorrel* («Oseille» Rumex sp).

With great clarity, the 1783 book on carbon uptake captures what it is like to subject a living organism to experimental chemical treatment:

> The chemist is a logician and, in the same way that he knows the violence he does to nature, he can also reveal the manner in which she responds to chemical treatment[14].

The themes of subjecting nature to violence as well as the difficulty of performing meaningful experiments on living organisms were to be recurrent in Senebier's writing on the theory of science. Here, the interdependence of these two major axes of Senebier's work, one on the practice of science (represented in his books on carbon uptake) and the other on the philosophy of science (*The Art of Observing* works) is the issue.

Observation *versus* experiment

The *Art of Observing* series, Senebier's chief contribution to the theory of science, was first published in 1772 as a long essay submitted in a competition organised by Holland's Science Society in Haarlem in answer to the question: What is required for the art of observation?[15] This essay, describing observation as a 'logic for the senses', was an early and brilliant attempt to describe the best means of observing and was written and submitted when Senebier was in his twenties, a decade before his first book on carbon capture. Apart from interesting discussion of the use of hypotheses and the inductive method there is relatively little explicit mention of experimentation. An exception is early in the essay where the limits of both observation and experimentation are compared and contrasted with Senebier stating that:

> Observation and experiment are two sisters who help each other[16].

Another passage of interest to any apprentice scientist today underscores the finite possibilities of observation and contrasts them with the infinite possibilities of experimentation:

> The experimentalist creates what is observed. The observer discovers the truth by established means. The experiment seeks truth by means of often of unproven efficiency. Observation teaches us the properties of things whereas experiments verify and measure their effects. Observation only shows the true work of nature-the world as it is; these are its limits. Alternatively, experiments can generate a thousand different happenings. The limits of experiments are the immense number of possible combinations of all the constituents of the Earth[17].

Surely, this is one of the best examples illustrating Senebier's early grasp of differences between observing and experimenting. The important points that Senebier brings out include the fact that experiments

[14] «Le Chymiste est logicien, & comme il connoît la violence qu'il fait à la Nature, il distingue aussi les modifications qu'elle doit introduire dans ces réponses»; Senebier 1783, pp. XIII-XIV.

[15] Senebier 1772.

[16] «L'observation & l'expérience sont deux Sœurs, qui s'aident mutuellement»; Senebier 1772, p. 11.

[17] «Celui qui fait des expériences, fabrique l'objet de ses observations. L'Observateur dècouvre la vérité par des moiens connus: l'Expérience la cherche par des moiens, dont elle ignore souvent l'efficace. l'Observation nous fait connoitre les proprietés des choses: l'Experience les vérifie & mesure leurs effets. l'Observation ne fait voir que ce qui est véritablement l'ouvrage de la Nature; le monde tel qu'il est, voila ses bornes: au lieu que l'Expérience peut se procurer mille spectacles différens; ses bornes sont le nombre immense des combinaisons variées des différens corps, qu'on trouve sur nôtre Terre»; Senebier 1772, p. 10.

[34] Senebier 1782, vol. 3, endpages.

test nature while observation lets nature simply test the observer and is not tested itself. The texts also hints at why it is difficult to offer a general framework to explain experimental methods by implying that observation provides a finite set of possibilities to the observer whereas the possibilities to experiment are infinite.

Finally, and in a different tone, Senebier wrote that:

> The experimenter forces nature to change its aspect... he subjects her to torture to tear out her secret[18].

Here, we are given an example of the use of the word 'torture' to evoke the way harsh experiments can work. While this analogy was not uncommon in the 18th and 19th centuries it is of particular interest in Senebier's works. The phrase presages much of what Senebier would write later and gives us the feeling that Senebier might have seen observation as a 'kinder' form of science than experimentation. Only with an analysis of his later work will we be able to look at this aspect in more depth. In any case, the historically important first essay on *Observing* shows that Senebier grappled with the comparison between observation and experiment from the beginning. Senebier's thoughts evolved further in the 1775 and more so still in the 1802 version of the *The Art of Observing*. However, the writing in the 1772 essay reflects the fact that the young Senebier had been exposed to outstanding teachers[19] and was influenced by a diverse and growing literature on the philosophy of science and scientific method[20]. Furthermore, indicating his stature as a theoretician of scientific method, Senebier has been discussed by Duchesneau[21] alongside J. G. Zimmerman (1728-1795) and both of these scientists shared similar notions of epistemology. Indeed, Zimmerman's influence was readily acknowledged by Senebier when it came to regarding nature as a book to be read by observation.

At this point one must acknowledge that in the first essay on *The Art of Observing* Senebier was constrained by the question he was supposed to answer for the academy in Haarlem and was thus obliged to focus only on observation. However, he published an extended version of his first essay only three years after the publication of the first version[22]. By this time, in 1775, Senebier was at full liberty to write about both observation and experiment, but the former, it would seem, remained the priority. Moreover, Senebier's cautious attitude to experimentation was maintained with a spirit very similar to that found in the 1772 essay:

> The experimenter forces nature to change its ordinary aspect[23].

Taking the 1775 book as a reference it might appear, again, that Senebier had a moral aversion to experimentation or perhaps just favoured observation over experimentation. Intriguingly, and as already pointed out[24], Senebier had little interest in the sort of observation traditionally practised by naturalists.

Why, then, did a scientist who pioneered new experimental approaches seem from his writing to be so focussed on observation? Did Senebier in fact prefer to write about observation but to perform experiments? In order to understand exactly where Senebier stood on experimentation it is informative to read the two series of books (those on carbon capture and those on the *Art of Observing*) as if they were one opus. A reason for this is that Senebier's own research must have led him to a growing awareness of difficulties one faces in the correct execution and interpretation of experiments. He would incorporate this thought into his evolving series on *The Art of Observing*. It was as if the study of leaves provided an outlet for the philosopher in him.

Describing experimental method: the limits of poetry

Already, Senebier's original 1772 essay showed that he realised the risks inherent in experimentation compared to observation. That is, the risk that a poorly conducted experiment could be completely misleading, a troubling prospect for any researcher. On the other hand, Senebier knew as well as anyone the power of experimentation; without it he would not be remembered for making one of the great discoveries in biology. Indeed, five years after his 1783 book, Senebier published a new work on carbon uptake that explicitly revealed his debt to experimentation. The title of this book begins with the word *Experiments* (*Expériences*)[25]. Years later in 1802, and near the end of his career, Senebier was to publish a new, expanded and final version of his 1775 *Art of Observing* book[26]. Experimentation would now figure prominently as the entire third volume in this new edition. With this in mind it is noteworthy that

18 «Celui qui fait des expériences, force la nature à changer d'aspect... il la met à la torture pour lui arracher son secret»; Senebier 1772, p. 9.
19 Maunoir 1810.
20 Grmek 1991; Huta 1998.
21 Duchesneau 1982, pp. 404-416.
22 Senebier 1775.
23 «Celui qui fait des expériences force la Nature à quitter son aspect ordinaire»; Senebier 1775, vol. 1, p. 5.
24 Pilet 1962.
25 Senebier 1788.
26 Senebier 1802.

the years between these two editions of *The Art of Observing* were consecrated to work on carbon uptake by leaves, that is, to gaining first-hand knowledge of doing experiments. The transition to Senebier's increased discussion of experimentation from 1775 to 1802 is illustrated by looking at the number of times the words 'experiment(s)' and 'experimental' appear in the tables of contents of the two *'Art'* books : not once in the 1775 version ; 11 times in the 1802 version.

In the 1802 *Art of Observing* book, and writing with first-hand experience, Senebier accorded a special consideration to experimentation:

> Experiments perhaps demand a more scrupulous attention than observations[27].

In the final volume of this book Senebier wrote about what is unique to experimentation. Prior to this, in volumes I and II of this work and in his two earlier versions of the *Art*, he wrote about what is common to observation and experimentation. We see that the original question that Senebier responded to in his first essay on observation was posed wisely. A similar question on experimentation would have set an almost impossible challenge as there are just too many possibilities in experimentation for one to summarise the best approaches. Indeed, Senebier did not (and perhaps could not) go as far as to suggest extensive methods for experimentation stating in 1802 that:

> ...it's impossible to give rules of a subject [experimentation] that can vary in a thousand ways[28].

Many today would agree with this and, taking this argument further, it has also been pointed out that too much organisation and too many rules stifle scientific progress[29]. Concerning observation and experimentation Senebier treated them as even-handedly as possible seeking the common ground between the two pursuits.

After success as an experimentalist, there is a paragraph in the 1802 version of *l'Art* where Senebier repaints his own sentiments about experimentation in a form echoing what he had published in his earlier versions of *l'Art*. The text is highly charged with symbolism:

> He who investigates nature subjects her to questioning to extract her secret. He makes nature speak a language that is new to her. He disturbs her, torments her, contradicts her. Sometimes she cedes to his solicitations and his torments. She bares herself. One finds the fruit of the work one has undertaken in the truth she is forced to reveal[30].

As much as it is interesting to analyse what Senebier wrote about, it is informative to look at the way he wrote. When it came to writing about science, Senebier used different prose styles to convey his thoughts on both observation and experimentation and also in comparing art and science. These writing styles varied from pragmatic (most of the time) to the poetic (more rarely). Sensitive to the arts, Senebier even commented on poetry[31]. He seems to have retained a moral or emotional sensitivity to experimentation, despite fully understanding its use. At first sight Senebier's commentaries could be taken to mean simply 'do not torture nature with harsh experiments'. Indeed, this interpretation is readily acceptable if not appealing to us today. Nevertheless, although surely correct, this reading is superficial. The greatest difficulty in forcing nature to explain herself in an experiment is that she might not tell the truth to the experimentalist.

There is nothing in Senebier's writing to indicate that he actively disdained experiments. On the contrary, the more his writing career advanced the more he mentioned experimentation. In fact, although using relatively few words dedicated to what it means to do experiments, *The Art of Observing* series tells us much about this process and offers deep insights into the difficulties that confront the experimentalist. While his own poetic phrasing is agreeable to read and highly quotable, many of the really important things Senebier wrote were not or could not be framed in a poetical form.

What *The Art of Observing* series tells us about experimentation?

Senebier succeeds well in providing us with good examples when it comes to conveying the power and limits of experimental approaches. The essential was captured in the distinctly modern phrases where what is strongly apparent is the need for caution. For example:

27 «Les expériences demandent peut-être une attention plus scrupuleuse, que les observations»; Senebier 1802, vol. 3, p. 108.

28 «...et il est impossible de donner des règles sur une matière qui peut varier de mille manières»; Senebier 1802, vol. 3, p. 288.

29 Feyerabend 1993.

30 «Les expériences fournissent les moyens de mieux sentir la vérité des découvertes qu'on peut faire, en permettant de juger les effets des causes dans leurs *extremes*»; Senebier 1802, vol. 3, pp. 46-47.

31 Senebier, 1802, vol. 3, p. 208.

> Experiments furnish the means to better feel the truth of our discoveries permitting us to judge cause and effect relationships in their extremes[32].

This text alerts the researcher to the fact that, in the process of experimentation, nature is often examined out of context. That is, if you work at extremes, you run the risk of generating artefacts. The following important text crystallises exactly what Senebier meant:

> To give experiments the greatest solidity one must, as much as possible, bring oneself close to nature, performing the experiments in a manner closest to the way nature itself works[33].

Distilling a growing awareness of the limits of experimentation within the broad scientific community, this statement, 'Senebier's rule', is a practical message to today's biologist. Although seemingly trivial, this thought process as used in designing or evaluating laboratory experiments is not automatic – in fact it is sometimes evaded by researchers.

Senebier's rule can be applied to the design of experiments. For example, a scientist might wish to treat living organisms with natural compounds and might use these compounds in concentrations far exceeding endogenous levels. This would contravene the principle. The researcher would first need to know what the normal levels of the compound were and to employ the compound at more physiological doses. Another example would be in tests of the survival of an organism under extreme conditions. Taken too far, such tests often remove both the organism and us from reality. A third and more interesting example would be the process of selecting mutants in genetic screens whereby a population of an organism is mutated and individuals displaying a desired characteristic are selected under perhaps extreme conditions. In order to follow the rule, a secondary examination of mutants obtained in such a primary screen would then be conducted under conditions 'closer to nature'. Experienced researchers can analyse all the facets of more complex experimental designs in this way although this approach is not restricted to the correct conception of experiments. It can also be applied when comparing the results of observations or experiments that have been conducted independently by different researchers. If such results are incompatible then the possibility that one or more researchers did not bring themselves close enough to nature could be considered. There are many more ways in which the rule can be applied. Its corollary is consistent with the fact that it is difficult to design and conduct meaningful basic research on organisms in space, for example.

Conclusion

Faced with an important scientific problem Senebier crossed the threshold from observation to experimentation. The transition between these two pursuits is captured brilliantly in his writing and this provides us with many insightful lessons. One of these being that deeper issues can sometimes be masked by emotional interpretations or poetic representations of what research really involves. The inevitable need for experimentation has not disappeared in today's world, so it is incumbent upon all of us involved in research to understand what both experimentation and observation demand of us - and of the organisms we study. Senebier's example still serves us well in the difficult undertaking that is science.

Note on translations

Translations are not always *verbatim*. For example 'du gaz acide carbonique' is translated to its modern equivalent 'carbon dioxide' and 'savant' is translated to the more recent word 'scientist'.

Acknowledgements

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[32] «Celui qui interroge la nature par des expériences, la met à la *question* pour lui arracher son secret, il lui fait parler un langage nouveau pour elle; il la gène, il la tourmente; il la contredit; elle cède enfin quelquefois à ses sollicitations, à ses tourmens ; elle se dévoile, et l'on trouve le fruit des travaux qu'on a entrepris dans la vérité qu'elle est forcée de révéler»; Senebier 1802, vol. 3, p. 13.

[33] «Pour donner aux expériences la plus grande solidité il faut se rapprocher de la nature, autant qu'il est possible, en les faisant de la manière qui se rapprochera le plus des procédés que la nature emploie pour la production du phénomène»; Senebier 1802, vol. 3, pp. 52-53.

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