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Dr Jan IngenHousz,
or why don't we know who discovered photosynthesis?

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Abstract

Who discovered photosynthesis? Not many people know. Jan IngenHousz' name has been forgotten, his life and works have disappeared in the mists of time. Still, the tale of his scientific endeavour shows science in action. Not only does it open up an undisclosed chapter of the history of science, it is an ideal (as under researched) episode in the history of science that can help to shine some light on the ingredients and processes that shape the development of science. This paves the way for a fresh multidimensional approach in the philosophy of science: towards an "ecology of science".

Introduction

Unravelling the story of Jan IngenHousz will twine strands of history of science and of philosophy of science together in equal measures. Imre Lakatos' dictum will be expanded fully in this particular examination of a very specific episode in the development of scientific knowledge: "Philosophy of science without history is empty; history of science without philosophy of science is blind."[1]

The materials on which this study is based are as diverse as coherent. The officially published books ands articles by IngenHousz form the obvious core of this study, but equally important are the letters, travel notes and diaries of IngenHousz that have been until now not properly researched. A third important element in this approach will be the reconstruction of the scientific experiments IngenHousz conducted, with the help of the detailed instructions he himself wrote for the proper design and use of the so-called eudiometer.

The main question driving this quest is why a man such as IngenHousz has got lost in the mists of time. The answer will hint at a fresh, "ecological" approach of the very fragmented ways philosophy of science has been done over the last decennia. It might sound ironic, but it is rather more a source of consolation, that a multi-faceted figure from the eighteenth century is able to inspire us to look afresh at scientific and philosophical practices of our own times.

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The roots of plant physiology

The Photosynthesis Bicentennial Symposium took place in November 1971. The Proceedings of the National Academy of Science that covered the symposium open as follows: "In early August 1771 Joseph Priestley, chemist from Birmingham, England, performed his famous experiment with the mouse and the mint plant. This experiment provided the beginnings of our understanding of that remarkable process whereby the organic matter of our biosphere is produced and our atmosphere continuously purified."[2]
Eugene Rabinovitch further sketches the sequential development of the leading ideas in the action of light on leaves.[3] The story begins about 1684, when a Flemish alchemist, Jan Baptist Van Helmont, grew a willow tree in a bucket of sand under a bell jar. He weighed the content in the pot before and after a year of the tree growing. The sand in the pot weighed the same after as before, while the tree had grown to sizeable proportions. Van Helmont wondered where the matter to grow the tree had come from and his conclusion was that it had been converted from the water used to irrigate the sand. His experiment would be only the first in a long sequence of experiments and explanations, resulting in publications spanning more than a century and of which a selection is listed in table 1.

Table 1
Experiments on plants, a chronology
1620 Jan Baptist Van Helmont
1727 Stephen Hales *Vegetable Staticks*
1754 Charles Bonnet *Recherches sur l'usage des feuillles*
1772 Joseph Priestley *Observations on different kinds of air*
1779 Jan IngenHousz *Experiments upon Plants*
1781 Willem van Barneveld *Proeve van onderzoek omtrent de hoeveelheyd van bedarf*
1782 IngenHousz *Some farther considerations on the influence of the vegetable Kingdom on the Animal Creation*
1782 Jean Senebier *Mémoires physico-chimiques*
1783 Senebier *Recherches sur l'influence de la lumiere*
1787 IngenHousz *Experiences sur les plantes* (ed 2, vol 1)
1788 Senebier *Experiences sur l'action de la lumiere*
1789 IngenHousz *Experiences sur les plantes* (ed 2, vol 2)
1792 Hassenfratz *Sur la nutrition des Plantes*
1796 IngenHousz *An essay on the food of plants and the renovation of soils*
1797 de Saussure *Recherches chimiques sur la végétation des plantes*

To the people at the Bicentennial Photosynthesis Symposium, Priestley's experiments were to be considered crucial in this sequence. In his 1776 book *Experiments and Observations on Different Kinds of Air* he describes several experiments in which he demonstrates that plants can restore the air that had been made unfit to support animal life by burning candles in it. He reported on an experiment which he did on 17 August, 1771, when he put a sprig of mint into a quantity of air in which a wax candle had burned out. Ten days later a candle burned perfectly well in it. A mouse was found to survive in this "restored" air. Priestley called it "dephlogisticated" air. (The description of the chemical element oxygen was still some years off in the future, Priestley thought the plant had taken phlogiston from the air which had been added by the burning candle.) That's the experiment that was celebrated in 1971.
However, in 1999, Calne, England saw a bicentenary homage to commemorate the death of the man considered by some to be the real discoverer of photosynthesis. Calne is the town

near Bath where Jan IngenHousz[2] died in 1779 on September 7. Howard Gest has made great efforts to highlight the importance of IngenHousz' experimental work in plant physiology.[4] There is no doubt both men are at the roots of plant physiology research. But why is Priestley till today a well known name in the history of science, while IngenHousz is virtually unknown, except for a few historians of chemistry and botany? Over the last years I asked every biologist, botanist of plant physiologist I met if they knew the person who discovered photosynthesis. They hadn't even heard his name. It is a curious phenomenon that nobody seems to know the man who discovered the most important biochemical process on this earth. It is after all, the one chemical reaction that produces the oxygen by which animal life, including you reading this, is possible. People know Newton, Darwin and Einstein, but don't know IngenHousz. This finding was the starting point for an exploration of the life and works of Jan IngenHousz. While mixing in insights from both philosophy and history of science, it might be possible to clarify some crucial aspects of this thing called science.

A doctor on the road

Life and works of IngenHousz are extensively described by Wiesner[5], Van der Pas[6] and Beale & Beale[7]. Jan IngenHousz was born on December 8, 1730 in Breda, the Netherlands. Being catholic, he couldn't study at the protestant universities such as Leyden or Amsterdam. He studied medicine at the catholic University of Louvain, where he received his MD degree in 1753. He continued his studies in Leyden and Edinburgh. Only after the death of his father, he left his medical practice in Breda and moved to London, invited by Sir John Pringle, prominent scientist, Royal Physician and president of the Royal Society. He became very experienced in inoculation against smallpox, a new and promising technique in London at that time. He met Benjamin Franklin, envoy for the American colonies, writer, publisher and self-made scientist. The two men shared many interests, such as inoculation, but also electricity. They were to become very good friends for the rest of their lives. IngenHousz fame as inoculator led him to travel to Vienna in 1768, recommended by the English crown, to inoculate the Habsburg royal family against smallpox. He successfully inoculated Empress Maria Theresia and her family. As a reward he was appointed as Court Physician and received many honours, gifts and a life-long annual income. From then on he was an independent man of means, free to do what he liked most: medical and scientific research.
He would lead a life of travelling between Vienna, London, Bath, Paris and Florence. He married the daughter of Jacquin, another Dutch expat at the Austrian court, professor of botany at the university. They never had children and probably haven't seen each other very much, as he was very often on the road for years on end. While travelling, he kept a diary, often writing in the language of the country where he was at that moment. In his diaries one can see how, arriving from Vienna in Paris, he switches from German to French. Apart from Vienna, England was to become his second home. He became a fellow of the Royal Society in 1779. He spend much of his time at country houses of friends.

On the track of oxygen

One of the important men in his extensive network was the Earl of Shelburne, Marquess of Lansdowne. He stayed at Bowood House in Calne, where Joseph Priestley - famous for his discovery of 'dephlogisticated air' - was librarian and scientist-in-residence, teaching Shelburne's children and working in his private laboratory.

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[2] IngenHousz is spelled here as one word, with a capital H in the middle, as IngenHousz himself signed his letters. His name can however also been found as Ingen Housz or Ingen-Housz.

Priestley discovered oxygen in 1774, although he didn't call it as such and probably did not really understand what he discovered. It would be Lavoisier who would later give this gas its name and a place in modern chemistry. At that pivotal point in chemical history, where oxygen was behind the horizon, almost ready to replace phlogiston, IngenHousz performed in the summer of 1779 a long series of painstakingly performed experiments on plants and wrote down his conclusions in *Experiments upon vegetables*. From this publication and the subsequent articles and correspondence, it is clear that he was the first to describe and understand the essentials of the process of photosynthesis. It is a most crucial chemical process on earth, as the central reaction that makes animal life possible, something which IngenHousz made abundantly clear.
On another of his transcontinental trips, he arrived in Paris in early summer 1789. He spend time with Antoine Lavoisier, who was busy developing the new chemical system that we still use today. He would overhaul the phlogiston theory as defended by Priestley and the rest of the chemical community. On July 14 the people stormed the Bastille. IngenHousz had to flee the French capital as he was travelling in a coach with the Austrian weapon on it. Joseph II and Marie Antoinette were brother and sister, so any sign of royalty was to the revolutionaries as a red flag on a bull. He could only just in time leave the continent that would go under in turmoil for many years.

A man of the Enlightenment

Back in England he continued his scientific work, trying to keep in contact with the European network of natural philosophers, which was becoming increasingly difficult as the revolutionary forces disrupted normal communication lines. Gall and bladder stones made his life miserable. Ill health prevented him from migrating to America (where is friend Franklin died in 1790) and to return to Vienna. He was never to see his wife, still in Vienna, again. But he did not become a hypochondriac in exile. He kept on writing, conducting experiments and frequenting his many friends. He spend much time in the country side, especially at Bowood, with the then Lord Shelburne, who had become Prime Minister. In 1795 he published a major work on the nutrition of plants. He was indeed the first to describe plants as 'solid air'. Apart from metallic traces and water absorbed through their roots, plants are built from the carbon that they derive from the carbon dioxide absorbed from the air during photosynthesis.
In 1798, he corresponded with Jenner, whose pamphlet on vaccination was all the rage. IngenHousz was concerned that the proven technique of inoculation would be ruined by a technique more fashionable than reliable. With due respect to Jenner (whom he never met) IngenHousz tried to underline the importance of clinical prudence in administering a new method, based on just one case. As in his botanical and chemical experiments, IngenHousz showed to be someone who instinctively applied very modern scientific methodology.
It was to be his last scientific feat. After a harsh winter in London, he travelled back to Calne in March and died in the first days of September 1799 in Bowood House.

The discovery of photosynthesis

IngenHousz' work was in line with the experiments Joseph Priestley had been doing in the 'elaboratory' at Bowood house in the beginning of the 1770's. Priestley had done many experiments that demonstrated that plants did something to the air that was fouled by burning candles or breathing animals. Plants somehow seemed to be able to restore the healthy, life-sustaining capacities of air. Priestley described it in the terminology of the chemical paradigm available at that time: plants 'dephlogisticated' the air. They restored phlogiston, the 'burning

principle'. His description was shrouded in a terminology that would soon be obsolete, but he pinpointed at the fact that plants and animals are interdependent, mediated by gasses. It was clear that Priestley did not really realise what he had observed, as he was not able to reproduce his results. That's because he was not aware that it was the light of the sun that was an essential ingredient of the dephlogistonification.
That's where IngenHousz got started. In a letter to Van Breda on 6 October 1783, he describes how his intuition and his preliminary understanding of the interconnectedness in nature, led him in setting up his experiments:

> "Ik was zeer vol van differente ideén zonder te kunnen overzien wat mij de experimenten zelf zouden aanduyden. Hoe zoude ik hebben kunnen op het denkbeeld vallen van planten in de schaduw en in het ligt te stellen zonder enig idee te hebben dat ik er iets onderschyde uyt zou hebben kunnen vinden. Indien ik geen idee gehad had dat wortelen vrugten bloemen andere werkingen hadden op de lugt als baderen, hoe zou het my ingevalen zyn om in zo en korte tijd zo veel differente ontdekingen daar omtrent gemaakt te hebben? in 't kort ik was zedert 1773 vol van allersoorten van ideén omtrent den invloed van der planten op den dampkring..."[3]

> "I did have many different ideas without being able to oversee what my experiments would show. How could I have had the idea about (testing) plants in the shadow or in the light, without the conjecture that I could find a difference in it? If I would have had no idea that roots, fruits and flowers have a different action on the air than leaves, how could I have had the inspiration to do so many different discoveries in such a short time? in short, I was since 1773 full of various sorts of ideas about the influence of plants on the atmosphere..."

He followed his intuition that sunlight had somehow something to do with it and that idea set him off for a long series of experiments during the summer of 1779. He conducted 500 experiments in which he systematically eliminated all non-relevant parameters to finally come to the conclusion that the green parts of plants, when shone upon by the sun, produce dephlogisticated air.

> "The production of dephlogisticated air from leaves is not owing to the warmth of the sun, but chiefly, if not only, to the light. No dephlogisticated air is obtained in a warm room, if the sun does not shine upon the jar containing the leaves." [8]

Moreover, he found out that plants breath just like animals. They do so at night and so reduce the quality of the air. That is exactly what he describes in the grand title of the book he published in the autumn of 1779:

EXPERIMENTS UPON VEGETABLES
Discovering their great Power of purifying the Common Air in the Sun-shine
and of Injuring it in the Shade and at Night,
to which is joined, a new method of examining the accurate Degree of Salubrity of the Atmosphere.

[3] For anybody reading Dutch, this may look very curious. At that time, there was no fixed Dutch spelling. On top of that, IngenHousz had been away from his mother country so long, speaking and writing so many languages, that he wrote some sort of phonetic Dutch in which consequent spelling did not seem to be very important.

It would be a perfect abstract for a modern day article. He not only succinctly describes his results but also tells us about the new method he uses to measure the quality of all these airs produced by plants and other organisms. The meticulous use of the eudiometer - the instrument to quantify the quality of the air - allowed him to produce long series of standardized data, which he reproduced time and again, step by step building up towards his conclusions.
His book would see translations in French, Dutch and German in the course of the following year. This international proliferation is partly due to the fact that IngenHousz was fluent in all these languages (although his spelling was far from perfect) and could follow up on all these translations. Still, he had a lot to complain about, as printing and publishing was often delayed by the very strict censorship rules in countries such as France. In the course of the following years he would publish more books and articles on the wonderful process of purification of the air by plants, on the relationship between the plant and the animal worlds and on the correct use of the eudiometer.
It would take another decade before a professional chemist from Switzerland Nicolas Théodore de Saussure would make careful analytical measurements of what the plant metabolism was really doing. He was the first to be armed with the sophisticated new theoretical and practical framework of modern chemistry and with the knowledge of the law of conservation of matter in chemical processes. De Saussure would put the icing on the scientific cake.

At the birth of modern science

Looking at IngenHousz' publications, at his correspondence and the discussions he had with fellow 'natural philosophers' it becomes clear that he works at the front line of the birth of modern science. While Hales, Bonnet or Priestley were occupied by collecting qualitative information about the world, IngenHousz, just like Senebier, Lavoisier or de Saussure, collected qualitative data. IngenHousz measured and measured again, calibrating his instruments, trying to measure as exactly as possible. This was part of his methodological approach. Where Priestley was experimenting haphazardly, setting up experiments inspired by his creativity and the inspiration of the day, IngenHousz build long series of experiments, eliminating one after the other irrelevant parameter, zooming in on the crucial aspects of the process he was studying. He had a hypothesis and wanted to confirm it. His observations were theory-laden, his reasoning went from deduction to induction and back, slowly building more insight in the transformational power of plants. Along the way, vague concepts such as 'airs' and 'earths' were replaced by more accurate concepts such as 'gases' and 'elements'. IngenHousz follows one of his intellectual masters, l'abbé Fontana who wrote in 1785:

> "Dans la siècle éclairé où nous vivons, ...on ne s'attache à présent qu'aux faits, & toute doctrine, qui n'a pas pour fondement des expériences réelles, n'est regardée que comme une pure hypothèse." [9]
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> "In this enlightened century in which we live, ... we hold on to the facts. And all doctrine which has no foundation in real experiences, can only be considered as pure hypothesis."

Experimental data, acquired through methodical inquiry, were very important for IngenHousz. He spends many pages in his books and endless paragraphs in his letters to describe his measuring apparatus and how he uses it, almost as a modern day protocol. He delineates what other experimentators do wrong and how that influences their results. He calculates the error margins and demonstrates how big the error can become if one handles the eudiometer inappropriately. (It is very likely he was inspired by the work of people such as Herschell. These astronomers and mathematicians calculated the error margins on the lenses of their telescopes. IngenHousz visited Herschell frequently and might well have been inspired by his approach to nature, importing new techniques into biology.) IngenHousz gives lengthy descriptions of the eudiometer, includes drawings and extensive information on how to assemble the apparatus and where to buy the right and reliable materials such as glass tubes and copper fittings. In his letter of 24 November 1786 to Van Breda he stresses the importance of being careful, both in doing experiments and in publishing their results:

> " Men kan niet te voorzigtig zyn in experimenten. Ik denk nog al vry gelukkig geweest te zyn in het punt van voorzigtigheid omtrent het uytgeven van experimenten. Ik weet nog niet dat Priestley, Senebier, of ymand anders iets tegen myne experimenten met fundament heeft in kunnen brengen. Indien u iets diergelyks zoud gewaarworden hebben in 't lezen of experimenteren, zou het my genoege zyn er van onderrigt te worden."

> "One can not be too cautious with experiments. I think I have been rather lucky with my cautiousness concerning the bringing out of experiments. I don't know yet if Priestley, Senebier, or anybody else has been able to formulate any fundamental criticism against my experiments. If you would observe anything of that kind while reading or doing experiments, I would be pleased if you would inform me."

Finding hypotheses disconfirmed is one of his greatest delights, as he realises that that is the only way we can learn how nature really works. That is undoubtedly the reason why in all his writings he tries to be as clear as possible, stressing the importance of straightforward specifications so that others can easily reproduce his experiments, which is essential to get any findings confirmed by independent third parties. It is hard not to read insights from contemporary philosophy of science into this way of thinking.

The pattern of a scientific revolution

IngenHousz took part in a scientific revolution. He offers an ideal sounding board for Kuhn's ideas about the Structure of Scientific Revolutions, especially as Kuhn used Lavoisier and the overthrow of the phlogiston- theory as one of the paradigmatic examples in his description of the evolution of scientific knowledge. IngenHousz sat astraddle on the paradigm shift from the phlogiston era to the era of modern chemistry, heralded by Lavoisier.
In 1779, IngenHousz is a true phlogistonian in the wake of Priestley, one of his friends and colleagues and the main defender of this theory. Meanwhile in Paris, Lavoisier was to do his crucial experiment producing oxygen in 1777 (inspired by a demonstration by Priestley when visiting the French capital). Still, it would take him until 1789 to develop it into a consistent theory that would overtake the old story of phlogiston.
In a footnote in the second Tome of the French edition of his book, IngenHousz mentions Lavoisier's system, as promising but still requiring more confirmation. In a letter of May 1792, he mourns over his friend Lavoisier who has been decapitated by the revolution, not giving IngenHousz much confidence in what was called 'democracy'. In a letter from 21 November 1792, writing from London to Van Breda, he endorses the new terminology fully, proving himself to have become a 'new chemist', applying the new knowledge to clinical purposes.

> " ... verscheide lugten gebruyken om verscheide ziekten te genezen die tot hier toe genoegzaam als ongeneesbaar gehoude wierde… het levensmakende principum of oxygene bedraagt 29/100 van de gewone lugt, de overige 73/100 is azote of dodelyke lugt…"
>
> "... various airs can be used to treat different diseases which have until now been uncureable... the life-giving principle of oxygen is 29/100 of the common air, while the remaining 73/100 is azote of deadly air..."

In the course of half a life time, IngenHousz switches paradigms. This is a far cry from the idea that old paradigms only disappear with the death of the last professors believing in them. It is also different from the idea that the switch from one paradigm to the other is based on irrational, argumentative elements. IngenHousz shows in his step from phlogiston to oxygen that it can be perfectly rational for a man to change his point of view. The new system offers him a better toolbox to handle the problem in front of him.
Could it be possible that the individual characteristics of a researcher could play a role in his or her attitude towards new ideas? All too typically, Priestley would stick to the phlogiston theory until his death. IngenHousz was a very different kind of personality. He was a medical doctor. Medical practitioners are forced by the inherent obligations of their profession to deliver results. Priestley was an old fashioned philosopher of nature, who could indulge in various theoretical reflections, not pressured by the need for a check with reality.
Moreover, IngenHousz was an independent man of means. After his successful inoculation of the Imperial family in Vienna, he received an annual stipend that made him virtually and literally, spiritually and materially, independent. He did not belong to a school or ideology. Priestley was a clergyman and a revolutionary. While IngenHousz was humble and non-polemic, Priestley was a revolutionary and outspoken public person. So was another of IngenHousz adversaries, Jean Senebier. Senebier was a catholic priest from Geneva, a librarian and man of letters, verbose and argumentative, trained to reach his goals by rethorics. IngenHousz in contrast, seems to be rather the man who is interested more in obtaining proper results than in discussing the theological implications of his findings.
Are these characteristics relevant to history of science? They obviously are, as they contribute to the way people think and act, to the way they develop their theoretical thinking and collect data. This is not to say that there is only one proper way of doing science. It only implies that science progresses through the contributions of many different approaches which can have their (dis)advantages at certain times and places.

In a network of science

When overlooking the three decennia of photosynthesis research in the second half of the eighteenth century, it is obvious that this is an almost contemporary research project. Various men all over Europe and even in the United States, are involved in a joint endeavour. IngenHousz cites and refers to his fellow researchers: Priestley, Bonnet, Fontana, Senebier, Van Barneveld, Lavoisier and many others. He has an intensive correspondence with like-minded philosophers all through the world, connected by an intensive network of diligences and travellers, bringing and taking letters and print proofs, books, specimen and gifts. He was visiting people while travelling and when he was in Vienna, his house was a much frequented stopping place for many people interested in the latest scientific news or demonstrations of the most recent experiments. In his publications and letters he responds to critiques from people such as Priestley or Carvallo, by setting up new experiments, rechecking his results and carefully analysing the experiments of his opponents.

As a matter of fact, in such a group of ambitious and curious men, rivalry is a natural thing. IngenHousz is too humble and reserved to polemicise on who is right or who was first, as he demonstrates in many of his letters. In private letters he complains about the attitude of some of his contemporaries who claim to be the first who discovered the benificial processes of plants (such as Priestley, Senebier and Van Barneveld). In the case of Priestley this has been exquisitely demonstrated by Howard Gest[10]. He shows how Priestley admitted in private that IngenHousz indeed had been the first to describe the beneficial power of plants in a letter to Giovanni Fabroni from 1779:

> "I have just read and am much pleased with dr Ingenhousz' work. The things of most value that he hit upon and I missed are that leaves without the rest of the plants will produce pure air and that the difference between day and night is so considerable."[11]

Priestley even promises IngenHousz to put things in order in a later publication. But the rectification never appears in print, IngenHousz is not mentioned, as decisively reported by Gest. In the mean time, he repeatedly claims in public to have observed and published before IngenHousz and he will keep on repeating this till 1800. Never does he give an accurate reference to IngenHousz' work, never does IngenHousz' name appear in the index of Priestley's works. IngenHousz himself, on the contrary, systematically refers to Priestley, with much respect.
IngenHousz refrained from making much public fuzz about the attitude of his rivalling colleagues. But they continued as they did, obfuscating IngenHousz' rightful reputation as the discoverer of photosynthesis in the eyes of the historians and the general public.

Science in society

All of this happens during a period in which politics and religion heavily influence whatever happens in society, also the scientific pursuits of people such as IngenHousz. One of IngenHousz' findings, that plants respire at night and so produce carbon dioxide, just like all other organisms, and therefore diminish the quality of the air, was strongly contested by many, among which Senebier. This priest couldn't fit the thought into his catholic world view that a plant could do something malicious. All things created by God were supposed to be beneficial, especially to mankind, the pinnacle of creation.
Other ideologies would cross IngenHousz' path too. When in Paris, the Revolution broke out, forcing him to flee to his birthplace Breda first and afterwards to England. The communicative network that spanned Europe and allowed for a quick exchange of information (letters could get in optimal circumstances from Leyden to Vienna in less than two weeks), was breaking down. One could not be sure that letters would arrive. By the end of his life, IngenHousz would feel rather isolated in England, far from his wife, family and friends on the continent.
IngenHousz' research was embedded in the society of his time. As a typical man of the Enlightenment, the goal of his research was to improve the life of all men. He applied his insights for various goals. Such as breathing apparatus for asthmatic patients, electricity and lighting rods (he installed the first one on the arsenal of Vienna), agriculture, inoculation... When, in the last years of his life, he starts a correpondence with Jenner about his new method for vaccination against smallpox, it is partly out of concern for proper execution of medical and scientific research (we would call it evidence-based clinical medicine now), partly out of concern for the health of so many innocent patients.[12]

The making of science

Philosophers tend to conceptualise things in order to get a grip on reality, at the same time deforming the view on that reality beyond recognition. Kuhn proposed a distinction between paradigmatic science and revolutionary science. That may have clarified some aspects of the scientific enterprise but also started a discussion that was mainly interesting for philosophers of science, as some tried to discern also pre-paradigmatic periods of science or others tried to console Kuhn's view with Popper's falsification principle. In the mean time, the scientific practice continued in labs all over the world, much more complex and too varied to be caught in simple philosophical distinctions and dichotomies. And demonstrating that it produced results, unhindered by the deep thoughts in the philosophy departments. The story of IngenHousz may clarify the work of another philosopher of science who found a way out of the eternal debates between nitpickers in the heritages of Popper, Kuhn, Feyerabend and Lakatos.

Peter Galison stayed very close to the actual practice of science, in his case the physics of the twentieth century. From a painstakingly and fine reconstruction of the history of physics, he ended up with some fresh philosophical ideas about the way science works.[13] He describes a relative autonomy of the experimental versus the theoretical physics. Both disciplines are deeply intertwined but at the same time enjoy a great autonomy. Theories suggest experiments and experiments confirm or disconfirm theoretical hypotheses. But essentially they both go through their own historical developments. And on top of that, Galison discerns a third layer of scientific activity: the instrumental dimension of science. Designing, constructing, adjusting and refining the instruments with which the experiments are performed. Also this field of activity is relatively autonomous of the two other, still at the same time deeply interlinked, as theory and practice influence the development of instruments, and vice versa. This autonomy has grown in the course of the twentieth century. At the time of IngenHousz, the men who formulated the theories where often the same that did the experiments and were just as well closely involved in designing the necessary instruments, if not in making these themselves. Experiments and instruments are therefore no mere epiphenomena of abstract theories.

The evolution of science takes different courses at different speeds in the three layers. As the case of IngenHousz demonstrates, the instruments stayed more or less the same, while the experimental data were refined, while the theoretical framework in which they were interpreted changed in the course of two decennia. The incommensurability question as phrased by Kuhn may be a problem when looking at the level of theories, but seems to disappear when one looks also at all the interlocking activities which are displayed in the making of science. No cement is needed in this 'dry wall' in which all elements fit together and create stability by their fitting forms.

That messy thing called science

Galison is a philosopher of science that goes beyond the one-dimensional, almost abstract approach of many of his colleagues, in which a scientist of blood and bones would hardly recognise him- or herself. These one-dimensional approaches has explicitly been inventoried and criticised by Susan Haack. She describes two standard major approaches to the philosophy of science, in endless discussion with each other and both too limited in scope to adequately render the full complexity of the scientific enterprise[14]. On the one hand, there are the "Old Deferentialists" who look at science with much respect. They stress the orderly and systematic, logical and rational way science tries to comprehend the way the world is. On the

other hand she observes the "New Cynisists", who describe in one way or another science as nothing more than a play of power and language, argumentation and persuasion.
Haack seems to be the first philosopher of science who tries to comprehend science as a common and everyday human activity in which some things are structured, some things are messy. While not offering an alternative framework, a encompassing co-ordinate system in which to situate and comprehend science, she offers a common-sense viewpoint: "After all, science is a thoroughly human enterprise: fallible and imperfect, ragged and uneven, but for all that, remarkably successful, as human enterprises go." She realistically describes and comprehends science as a method to gather trustworthy knowledge about the world. It leaves room for other forms of knowledge (a poem about a bird may contain some knowledge about the art of flying, but would be not the thing to trust to build an airplane). It discerns in science also the crucial and differentiating potency to find ways of improvement. As science asks for a permanent stance of self-criticism, it is ideally suited to unmask mistakes or illusions and find ways to improve on the errors of yesterday. Science is a systematic way of doing it better next time. It is the only human game in which this kind of systematic doubt is fundamentally incorporated, nicely demonstrated by IngenHousz' end remark in his 1779 book:

> “I am far from thinking that I have discovered the whole of this salutory operation of the vegetable kingdom; but I cannot but flatter myself, that I have at least proceeded a step farther than others, and opened a new path for penetrating deeper into this mysterious labyrinth.”

He knew that every question that finds an answer only leads to the next question.
The life and works of IngenHousz may nicely illustrate how science really works. I suggest to use a framework with four dimensions in which the multidimensionality of real life events in the discovery of photosynthesis might be understood:

1) the scientist as individual,
2) science as the result of a group of people working on the same subject,
3) science as a theoretical and practical set of things to know and to do (theory, hypothesis, experiments, etc.) and
4) science as an activity embedded in society.

This could be seen as an expansion of Haack's dichotomy. The Old Deferentialists concentrated either on the formal, logical or philosophical content of science. Another strand of this approach can be found in the biographical approach of historians who describe the heroic lives of the men and women of science as lonely prospectors in unknown territory. The New Cynicists concentrate on science as a group-driven phenomenon and/or on science as an activity that can or should be understood as an integral part of human society, a game of money, power and suppression. Refining Haack's observation into a four-dimensional framework is no coincidence. It derives from experience with one of the most messy things on earth: living nature, as studied by ecology.

Science as an ecosystem

Science may be studied as an ecosystem. According to the definition by Francis Evans from 1956 "In its fundamental aspects, an ecosystem involves the circulation, transformation, and accumulation of energy and matter through the medium of living things and their activities."[15]
Ecology studies an ecosystem as the interplay between four factors: individual organisms (a squirrel, a fungus or a beech), groups of animals and plants (the population of all squirrels or beech trees), their environment (the geological, climatological and geographical surroundings in which all these populations live) and the flows of energy and information that link all

components together and define their interactions and dynamic equilibrium (the squirrels that are eaten, whose leftovers decay through bacterial and fungal action and are recycled into a new little beech). Each can be studied on its own, but we will never get the whole picture if not all these detailed findings are put together. It will be necessary, even inevitable, that somebody studies the doings of the squirrels in great detail. And the fate of the forest will be mirrored by the lives of the squirrels. But that doesn't mean to say that you can understand the forest if you understand the squirrel.
In an ‘ecological’ approach to the philosophy of science this can be translated as the interplay (through their common ground in theory and practice) within society (which decides where the money or the attention goes) of a group (science is defined by its creative and critical co-operation within and over disciplines) of individuals (each with their own idiosyncrasies). (See table 2) Some philospohers of science will have to look into the details of the logical format of theories, others will have to reconstruct the historical chronology of events, only together they will be able to shed some light on the complexity of this ambitious human enterprise called science.
Looking in this way at photosynthesis research in the second half of the eighteenth century, might help to explain how this chapter in the history of scientific enquiry is representative for what science as a method for acquiring trustworthy knowledge can do. It may also explain why very few people know about the discovery of the most important biochemical process on earth. Ad why - though all ingredients seem to be present to make IngenHousz a household name in the long and glorious history of scientific discovery- his name hardly figures in the history or biology books.

table 2
science as an ecosystem: four parameters

individual	science as inspiration	the lonesome investigator, with all his or her idiosyncrasies
population	science as teamwork	people together, in one lab, in a department, within a discipline
interactions	science as theory & practice	the content that binds them, the flows of information and energy that link them up
biotope	science as politics	within the wider world of science and within society

Paths to oblivion

A sure way to be forgotten, is to behave in such a way that nobody remembers you. IngenHousz was a humble person, not interested in fame, pomp or circumstance, enjoying his independent status, as testifies this passage from a letter to Van Breda on 20 Febryary 1788:

> "My werd aangeboden B. [Baron] Van Swieten op te volgen en dus het opperbewint aller universityten en alle geleerde van een magtig en wyd uytgestrekt ryk te voeren. De Keyzerin bood niet alleen een grooter inkomen maar ook adelyke titels en publike decoratien. Ik sloeg dit alles af zeggende dat ik niets meer verlangde dan de continuaties van wat ik reeds ontfangen had ; en ik heb door een nu 20 jarigen

ondervinding bevonden dat ik onyndig gelukkiger en geruster geleefd heb dan ik zou geleefd hebben indien ik door heerszugt en hoogmoed my had laten verlyden."

"I have been offered to succeed Baron Van Sieten and thus manage the supreme command of all universities and all savants in a powerful and vast empire. The Empress not only offered me more income but noble titles and decorations as well. I reclined saying that I desired nothing more than the continuation of what I had already received ; and that I learned after 20 years of experience that I am infinitely more happy and serene than when I would have seduced by imperiousness and haughtiness."

He was low-key and introvert, enjoying friendships, shying away from stardom. This stands in contrast to some of his fellow researchers of that time. One of his colleagues and competitors was Jean Senebier, who claimed that he was the first to understand the beneficial processes in and by plants. IngenHousz is rather upset about this claim, as Senebier clearly did not perform all necessary experiments, probably just copied the work from IngenHousz' book. A major reason for thinking so was that Senebier disputes the findings by IngenHousz that plants respire in darkness - a phenomenon he should have seen clearly if he had just done the necessary experiment. While plagiarising IngenHousz' work, Senebier only mention him as someone who inspired him, while he himself had had these ideas in the first place. IngenHousz read Senebier's *Memoires Physico-Chymiques*, published in Geneva in 1782 and scribbled abundant notes in its margins[4], noting in 1783:

"Le premier article de l'ouvrage est rempli de tracts manifestes de vanité, d'envie, d'amour propre, de pretensions pour s'attirer autant qu íl prent de l'honneur des decouvertes de Mr IngenHousz[5]. "

"The first chapter in this book is full of manifest traces of vanity, envy, egotism and pretensions to attire as much as possible from the honour of the discovery of Mr IngenHousz."

He further minutely analyses the rethorical trics Senebier uses to make the world think he was the man who discovered photosynthesis, while resolutely indicating the moments where he must have been making mistakes, either in performing the experiments properly or in interpreting the results. To IngenHousz it is clear that Senebier has just copied his description of many experiments from his book of 1779 and not even bothered to reproduce them - for him a hallmark of proper scientific conduct. Senebier, according to IngenHousz,:

"il n'avoit que des ideés, comme il l'avoue pag. 3 lui même. Le date de ces prétendues lettres rend ces idées tres problematiques."

"he did not have but some ideas, as he admits on page 3. The date of the assumed letters [in which Senebier argues to have pronounced these ideas] makes these ideas very problematic."

Later in 1784, in a letter to Van Breda, his friend, fellow doctor and producer of the Dutch translations of his books, he writes:

[4] This unique copy is being kept at the library of the City Museum, Breda, the Netherlands
[5] IngenHousz writes here about himself in the third person, because he makes these notes as a rough draft for an offical article to be published later.

> "En observant donc de plus en plus, que la silence, que j'avois observé pendant si longtems, par pure politesse & ménagement pour un savant dont j'honore les talents avec toute la republique des lettres, ne servoit qu'à faire envisager mes decouvertes comme insoutenable; je me trouvai à la fin forcé d'exposer au public des preuves ulterieures de mon systeme. Il m'étoit pas possible d'y parvenir qu'en tachant de demontrer la foiblesse des arguments & des experiences, que Mr. Senebier a pu trouver bon de publier pour combattre les miennes."

> "I have kept silent for a long time because I have very much respect for Mr Senebier as savant and honoured member of the Republic of Letters. And I have kept silent for such a long time from pure politeness, but this has only resulted in letting my discoveries come out as insustainable. I am now forced to come out with the ulterior proves for my system."

IngenHousz prepares a "polemic article", but in the end does not send it out for publication. He doesn't like the fuzz and the stress. He has too many other, more fruitful things to do and is plagued by his gall stones.
IngenHousz was not the only individual involved. As has been said, Joseph Priestley recognizes the fact that IngenHousz rightly claims to be the first to have described the beneficial processes in plants. In a letter to IngenHousz he writes:

> "All the time I was making these experiments I wrote to my friends about them; particularly to Mr Magallan and desired him to communicate my observations to you as well as to others; but i believe you had not heard of them; so what you did with <u>leaves</u> was altogether independent of what I was doing with <u>whole plants</u>. The same summer and the same sun, operated for us both and you certainly published before me."[16]

Priestley promises in several letters to put things in order in the next volume of his publications (part IV). It is obvious from the letter IngenHousz wrote to Van Breda on 24 May 1786. He has been informed that Priestley's new book came out in London. He is very curious if Priestley mentiones IngenHousz at all, as he promised to do two years ago. He himself can not quickly get hold of the new publication in Vienna, so he hopes to hear from Van Breda, as he suspects it is more easily available in Holland.
On the sixth of July, Van Breda must have answered him and IngenHousz replies:

> "...geen reactie van Priestley omtrent het geen wy reeds hadden opgemerkt omtrent zyne ingewikkelde manier om sig het sonneligt op planten toe te eygenen. hy moet met de zaak verlegen geweest zyn en niet wel geweten hebben hoe sig te zuyveren. Dit denk ik te meer omdat hy volgens zyn brief aan my, zeer wel weet dat wy hem als een afgunstig physicus hebben doen voorkomen, zeggende zelfs, dat myne vrienden hem hielden als <u>den sultan die geen competiteur tot zynen troon oner zyn ogen dulden kan</u>."

> "... no reaction from Priestley concerning what we already had remarked about his convoluted manner to appropriate the sunlight on plants. He must have been embarrassed about the situation and uncertain how to exculpate himself. I am even more convinced because he, according to his letter to me, very well knows that we exposed him as a envious physicist, even saying that my friends took him for <u>a sultan who would not tolerate before his eyes a competitor to his trone</u>."

And even in his mother country Holland, somebody tried to claim the discovery of photosynthesis or to "rob him from the sunlight" ("dat ik my van het sonneligt niet kan of mag laten beroven" 22 October 1785). Willem van Barneveld manipulated the dates of handing in his publication on the purifying powers of plants at the secretary of the Verhandelingen van het Provinciaal Utrechtsch Genootschap, in order to claim primacy.[17] He too, doesn't mention IngenHousz, whose experiments he copies. As Smit already noted, IngenHousz was living and working in a period during which numerous new discoveries were made and in which some investigators did not shun any means to claim priority for this or that discovery.[18] And IngenHousz knew that too, as he writes to Van Breda on 11 May 1785:

> " Men heeft er fontana al publiek van beschuldigt zyne uytvindingen te datummen op tyden wanneer hy er waarschynlyk nog niet op dagt, en van ontdekkingen aan te kondigen die hy niet heeft gemaakt. Ik heb reden om te denken dat priestley er ook niet vry van is, terwyl de H. Franklin, de laatste keer als ik in Parys was, een brief bequam van Priestley, ontdekkingen bevattende, welke brief omtrent 5 maanden voor den ontfangst gedatumd was. Ik wil hierdoor maar alleen beweren dat het niet onmogelyk is dat Senebier al vroegtydig de wind van myn ontdekking, misschien wat verward, heeft gevat. Hoe dit ook zy, hy had de couragie niet van in zyn boek zig op iets anders als <u>ideén</u> te beroepen., zig waarschynlyk niet betrouwende van enige proeven te spreken, omdat zyne vrienden hem zoude schuldig konnen kennen van onwaarheden te schryven."
>
> "Some have been accusing fontana in public of putting dates on his inventions when he probably had not even thought about it and of announcing discoveries which he did not make. I have also reasons for thinking that priestley is not free of this weakness, while Mr. Franklin, when I was last time in Paris, received a letter from Priestley, containing discoveries, dated about five months prior of the date of reception. Therewith I just want to argue that it might not be impossible that early on Senebier can have picked up rumours about my discovery, however muddled. Whatever happened, he did not have the courage to call upon anything alse but <u>ideas</u>, probably not trusting to refer to any experiments, because his friends would be able to know him to write untruths."

Local heroes seem to have overtaken IngenHousz from the left and from the right, highlighting one of IngenHousz' vulnerabilities. He never stayed long enough in one country to build his popularity. Moreover, he was no societies-man. He preferred to work on his own and keep some friendships alive with people that really interested him, such as Franklin. As he was not associated with learned societies, nobody there was inclined to defend his honours. He was a member of the Royal Society in London, but did not have very often the occasion to appear there live, as he was travelling most of the time.
Another, very prosaic but nonetheless quite realistic reason why IngenHousz' name got forgotten is that he left no children who could keep the name of their father high. It is only recently, 200 years later, that some great-great-nephews dusted off the name of the man they fondly call "Ome Jan" (Uncle John). If no nation, no society nor your family stands up for your name, how could it survive the erosion of history?

Who discovered what?

Apart from all those inter- and intra-personal circumstances that can partly explain IngenHousz' historical fate, a philosophical argument should be made. Although IngenHousz may have discovered photosynthesis, he didn't know. He rightfully concluded (which nobody

else did) that the green parts of plants in the light of the sun produce oxygen, which is beneficial for other forms of life; and that they produce carbon dioxide when in the dark. He did not have the slightest idea on what really happened inside the plants. He did not -could not- know that a very intricate mechanism of green pigments inside the leaves, powered by photons from the sun, through a cascade of biochemical reactions, produces carbohydrates from oxygen and water. This process would only be baptised "photosynthesis" in 1893 by the American plant biologist Charles Barnes[19] after doctor Julius Robert von Mayer in 1845 had identified the capacity of plants to turn electromagnetic power into chemical power[20]. IngenHousz' discovery would only get a proper name some hundred years later. And as is well known, things without a name don't exist in the minds of people.
One could rightly defend the argument that the discovery of photosynthesis was a long sequence of events in which a multitude of researchers, in a transnational effort that lasted from the beginning of the 17th century till the end of the 19th, slowly but surely unravelled this wonderful natural process.
Science is a step by step endeavour. Depending on how you define photosynthesis and how you choose the essential aspects of it, another person may come out as the discoverer. This nevertheless stresses the fact that science is done by many like-minded people, working together as a team spread out over space and time. IngenHousz, Priestley, Senebier and many others may not have been the best of friends, they stimulated each other to reconsider their claims, improve their experimental set-up and refine their hypotheses. The competition may have been unpleasant at times, it spurred the drive to do better. The quarrels were all too human, the result transcended what any individual on his own could have achieved.
The discovery of photosynthesis took more than a century and involved one Englishman, one Dutchman, two Swiss, one American and one German, among others, two were churchmen, two medical doctors, a professional chemist and a biologist. It is another characteristic example of the international and interdisciplinary nature of major scientific progress, driven by the colourful personalities and individual curiosity, sometimes hindered and then again propelled by social developments and tensions.

Towards an ecology of science

Another biologically inspired metaphor nicely illustrates this complexity. An old story says that six blind men were asked to determine what an elephant looked like. Each was touching a different part of the animal's body. One feels a pillar, another a rope. The third feels a tree branch, the fourth a hand fan. Another says he touches a wall, the last says he holds a solid pipe. A wise man explains that all of them are right. The reason every one of them is telling it differently is because each one touched a different part of the elephant. The elephant has all the features mentioned, but to understand what the elephant is, all the different perspectives have to be integrated. This story has roots in Jain, Hindu and Buddhist traditions and got a place in Western thought by the children's poem by 19th century poet John Godfrey Saxe:

> It was six men of Indostan,
> to learning much inclined,
> who went to see the elephant
> (Though all of them were blind),
> that each by observation,
> might satisfy his mind.
>
> ...

And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong!

Being partly right may mean one is totaly wrong. Reconstructing the remarkable story of Jan IngenHousz demonstrates this same complexity, all too typical of all things human. Clearly, science is no exception at that. Trying to chart this complex reality, led me, as a biologist, to the scientific discipline specialised in living complexity. Ecology is the study of the complexity of living systems in their interaction with the rest of the world. That sounds like a rather good description of science: a complex but methodical manner in which human beings interact with the world in which they live, in order to try to obtain some reliable knowledge about it. Philosophy of science has been trying to understand this particular human behaviour. As some philosophers of science have been indicating, the traditional ways of doing this were flawed, by being too limited or fragmented, just like the six blind elephantologists. As has been hinted at in this article, an ecological approach offers a workable toolbox to come to grips with the multifaceted reality of the scientific enterprise. The fate of IngenHousz and of photosynthesis research can be better understood if one takes into account as well the individuals involved, as their social, cultural and historical context, as interwoven in social interactions and interconnected by the theoretical, instrumental and practical requirements of their scientific research.

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