Leviathan Against the Air Pump

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The dispute between Robert Boyle (1627-1691) and Thomas Hobbes (1588-1679) was a key event in the history of science. Although ostensibly about the nature of the vacuum, the dispute was fundamentally an argument about how useful knowledge might be obtained. This article is based on a lecture course on *The Enlightenment*, I used to give at the University of Essex. An HTML version of this article, including pictures of Boyle, Hobbes and the air pumb, is available from www.colin-baxter.com/tips_and_ideas/boyle_hobbes.html.

1 Introduction

Revolutionary change swept through Europe and the American colonies during the Seventeenth and Eighteenth Centuries; a time that also saw the beginning of modern science, a revolutionary new intellectual activity that was to become the dominant and most successful mode of thought throughout the world. The scientific revolution began with the establishment in the Seventeenth Century of experimental science: a prescribed systematic approach, or method of investigation, that formed an integral part of the cultural change we now call the Enlightenment and which became codified in terms of what is now known as the *experimental method*.

A key event in the formation of the scientific revolution was the dispute between Robert Boyle (1627-1691) and Thomas Hobbes (1588-1679). This dispute, which took place in England in the decade following the Restoration of the Monarchy in 1660, was ostensibly about the nature of the vacuum. It was, however, much more than this. It was fundamentally a dispute about the nature of knowledge, and of the methods by which useful knowledge might be

obtained, and, as such, it strikingly encapsulates the philosophical problems thrown up by the emergence of experimental science.

Central to the argument were the related questions of what was meant by experimentation and what was the nature of its significance. Boyle appears as the major practitioner of systematic experimentation, and possibly its most important propagandist, while Hobbes is the main opponent of the experimentalists. To people like Hobbes, experimental facts could never form the basis of real and useful knowledge: to the experimentalists like Boyle, knowledge was impossible without experimentation.

By emphasising what they had actually observed in their experiments and ignoring the authority of ancient authors, the proponents of experimental science introduced a new and revolutionary way of thinking about the world. These *skeptical chemists* who made no theories had little use for the philosophical precepts of the day. To argue their case, to distinguish themselves from their protagonists, they adopted a simple, skeptical style of writing of which Robert Boyle was a master. Unlike their opponents, the practitioners of the new experimental science chose to write in English, using the plain language of the artisan.

In keeping with this position, Boyle's published results of his experiments on the air-pump did not contain any polemic on rival ideas then current about the nature of the vacuum. He cut through the debate between the plenists and vacuists by simply ignoring the previous philosophical definitions and redefining the vacuum in purely mechanical terms. In so doing, Boyle claimed for science the right to be the sole provider of useful knowledge.

2 The Style of the Experimenters

A present-day scientific paper is unintelligible to the layman. This ought to be surprising since it is simply piecemeal reporting of what its author, the experimenter, observed in the course of conducting the experiment. That the unintelligibility to the layman is the result of the scientific paper containing an enormous amount of unfamiliar detail does not detract from the fact that it is written in a direct style, with no flowery prose and no complex constructions. This deliberately aids the scientist in his task of convincing his readers that he indeed performed the experiment and observed the stated effects. The use of the vernacular gives an air of modesty to its author, who is seen as a sober individual and one who therefore can be believed. These characteristics of a modern scientific paper have remained almost unchanged since they were first developed in the Seventeenth Century by Robert Boyle.

When he wrote, Boyle deliberating set himself the tasks of not only reporting what had happened when he performed a particular experiment, but also to convince people that it had actually happened. By the Seventeenth Century, there was a long tradition of people reporting as factual something that they had not observed, or indeed could never have observed. Boyle therefore needed to convince his readers that he had actually seen what he described. He also needed to convince his readers why they should care about what he had seen. Why bother with these peculiar and artificial experiments that could show at great cost only things that nobody much cared about?

Boyle set about these tasks by simply using the personal pronoun in his writings to indicate that he himself had actually observed what he was writing about and that he was not going on hearsay. The use of the personal pronoun was a revolutionary idea. In its use, Boyle and other experimentalists were opposing a long history of natural philosophy, in which writers discussed observations claimed to have been made by other people, and often by people who were long dead. By claiming that *he* had *seen* it and not just read it, Robert Boyle was as responsible as anyone for overturning the reliance on ancient authorities.

Boyle greatly influenced a group of scholars and thinkers, who were known either as the *invisible college* or as the *philosophical college*, who met regularly to discuss and perform experiments, first in a public house in Cheapside, London, later in Gresham College, Oxford. Many of the members of the *invisible college*, including Boyle, were later responsible for founding the Royal Society, shortly after the Restoration. The Royal Society included people such as Sir Christopher Wren, the diarists John Evelyn and Samuel Pepys, as well as those who today we would label as scientists, like Hooke, Sir Isaac Newton and Boyle himself. In fact, Pepys was the President of the Royal Society a few years before Newton held the office.

Boyle and the other experimentalists sought to open up clear blue water between themselves and the writers of philosophical systems. Writers of systems used flowery language; they frequently used the *dialogue*, together with metaphysical and allegorical forms; they were general and expansive in their arguments, often quoting the ancients; and they wrote in Latin. These people were therefore seen by the experimentalists as overly confident individuals whose ambitions extended beyond what was proper or possible.

3 Boyle's Experimental programme

Robert Boyle maintained that proper knowledge could only be generated through experiment and that the foundations of such knowledge were to be consti-

tuted by experimentally produced facts. Facts mirror nature: *What men make, men may unmake; but what nature makes no man may dispute*. Although facts are certain and other items of knowledge less so, how were facts to be generated from an experiment? The answer according to Boyle and the programme of experimental endeavour that he and others promoted was simply to repeat the experiment. By conducting the same experiment over and over again then the certainty of fact will emerge. This is a subtle but the fundamental characteristic of the experimental method.

Before the mid-Seventeenth Century , the designations of *knowledge* and *science* were rigidly distinguished from that of *opinion*. Hence, from the former, we could assert an absolute certainty of demonstration, exemplified by logic and geometry. The important point to remember is the feature of absolute certainty that we could expect from a demonstration. In other words, a demonstration need not be repeated. Indeed this was a major criticism of Hobbes against the experimental programme of knowledge advocated by Boyle. If the experiment had to be repeated over and over again in order for a fact to emerge then in Hobbes' view the fact and the experimental process were worthless. Truth was evident immediately and would not hide itself under layers of repeat performances.

If facts are the only reliable knowledge, as the experimentalists maintained, and if facts were to be obtained by repeating experiments over and over again, then one must ask when should we stop experimenting. In other words, when do we know that we have a fact? Boyle proposed that matters of fact were to be established by the aggregation of individuals' beliefs. Members of an intellectual collective (for Boyle, this meant the Royal Society) had mutually to assure themselves and others that belief in an empirical experience was warranted. In this way, Boyle claimed that he could build up a scientific community, on the basis of reporting experiments, and all inside the community could except them as factual.

4 The Vacuum and Boyle's Air-Pump

The simple argument advanced by the Greek school of Parmenides (*fl.* 500 B.C.) said that there was no vacuum (or void) since the vacuum is nothing and nothing cannot exist. To them, the Universe was one continuous unchanging whole. The counter argument was advanced by Democritus (*fl.* 460 B.C.) and was intimately linked to an atomic view of matter. The void was seen to be necessary to assure the discreteness of atoms. The followers of Pythagoras (*fl.* 6C. B.C.) claimed that the void existed between the integer numbers.

Aristotle regarded space and time as continuous and defined the continuum

as infinitely divisibility. He therefore held against the existence of the vacuum and such was his standing that the Church adopted this view. However, until the late Middle Ages, when the structure of the continuum was beginning to be perceived as being the same as that of real numbers (which include fractions as well as integers), the meaning of what was meant by something being infinitely divisible produced much debate. Many well-known and seemingly intractable problems, such as how many angels could sit on the pin of a needle, were argued over in the search to understand the nature of the continuum.

Although the mainstream of mediaeval thought denied the existence of the vacuum, some scholars did distinguish between intra-cosmic and extra-cosmic voids. The extra-cosmic void was bound up with the problems of linear motion of the cosmos (that part of the universe existing below the heavenly vault) and whether the universe sat within a void. The existence of intra-cosmic voids was regarded as impossible, since it would imply the material presence of something beyond the universe. On the other hand, the existence of an intra-cosmic void was thought to be possible, since it involved either the notion of vortices (circular movements within the cosmos), or the notion that if God were to destroy the cosmos then a void would be created for a short period of time before collapse.

These ideas were far from being consistent, or well constructed, but by the end of the Fourteenth Century it had become to occur to some churchmen that Aristotelean ideas presented claims that were incompatible with the omnipotence of God. In 1277, Stephen Tempier, Bishop of Paris, issued a series of influential condemnations, including several key claims of Aristotle, because they implied limitations to the absolute power of God. Chief of these was the condemnation of the proposition that God could not move the cosmos in a straight line since it would leave an extra-cosmic void. Nevertheless, these technical details were appreciated by very few people, and even by the Sixteenth Century, the Franciscan monk Rabelais encapsulated both the teaching of the Church and the accepted view of most learned men with the phrase, *Nature abhors a vacuum*.

Then in 1644, six years before the death of Descartes, Torricelli invented the barometer. The one-time secretary to Galileo had inverted a long glass tube completely filled with mercury over a bath of the same liquid. The mercury in the tube fell to a height of about thirty-inches above the level of mercury in the bath, leaving a space at the top of the tube. What was in that space? Torricelli claimed that a vacuum existed in the space within the tube. Not everyone was convinced: hated debates ensued and the Torricelli barometer became the talking point of the decade.

So too had been Boyle's air-pump, which he had invented some years be-

fore Torricelli's barometer. The action of the air pump provided a remarkable spectacle. As early as 1661, the Danish ambassador had been shown the air pump, and in 1667 the Duchess of Newcastle, who was probably the first woman to be admitted to the Royal Society, was, according to Pepys, similarly entertained. Boyle's air-pump was fiendishly difficult to construct and expensive to build. We see immediately here a possible inconsistency with the humility claimed by the experimental programme. Experiments were to written up in such a way as not to conceal anything, so that the experiment might be repeated by anyone. Repeatability is a key feature of the creation of matters of fact. However, already, in the Seventeenth Century, the apparatus costs were prohibitive to most individuals.

Boyle decided to use his air-pump to explore the Torricelli barometer. It was a worthy problem, and to solve it, Boyle simply placed the Torricelli barometer inside the globe of his air pump and started pumping. He then saw that the level of mercury in the tube fell while that in the bath rose. Eventually the two levels were the same. Whatever was inside the Torricelli space was now inside the globe of the air pump. Was it the vacuum? Boyle would not say. He studiously claimed not to be taking sides, and a skeptic, he would neither line up with the vacuists nor the plenists. All he would say was that once he had pumped the air from out of the globe there was not anything in there that he was interested in. Rather than an irritating pretence on his part that he did not have an opinion, Boyle was actually saying a great deal. He was refusing to engage in the dispute about the vacuum on the terms it had been conducted so far. It was this refusal to play philosophy under the rules of the time that so enraged Hobbes.

5 Hobbes' Criticisms

Hobbes denied that the status of philosophy was now dependant on the outcome of the experimental programme, claiming that it was pointless to perform systematic series of experiments, since if one could in fact discern causes from natural effects then a single experiment, *i.e.*, a demonstration, would suffice. Hobbes also refused to accept that it was possible to establish a procedural boundary between observing positive regularities (the facts) and identifying the causes that account for them (the theories). He persistently treated the experimentalists' hypotheses and conjectures as statements about real causes.

The history of science has not been kind to Hobbes. Although he might seem to be correct in thinking that the facts about air pressure are rather marginal to the concerns of most people and facts in themselves are incapable of giving a direction or a meaning to society, he failed to understand the scientific

method or to foresee its material and intellectual benefits.

The notion is sometimes advanced that Hobbes was justified in doubting the facts as Boyle reported them, and that Hobbes was therefore right in believing that Boyle's experimental programme was more than the results of a few experiments. To Hobbes, Boyle's programme, involving an intellectual collective, divided the state and its people. The openness of experiment which Boyle claimed was contrasted by Hobbes to the reality, as he saw it, of a highly specialised and closed privileged class. We have seen that already at the birth of experimental science, the financial costs of the experiments, and the required technical knowledge, put them out of reach of most people, contrasting with Boyle's notion of open and reproducible experiments. However, reproducible of experiments meant that they could *in principle* be reproduced by anyone; there were no requirements of *grace* or devine sanction. The necessary experimental skill or finances were of this world only.

Hobbes, however, was correct in maintaining the importance of theory. No science is possible without a theoretical framework, and it is no surprise that in physics, the most successful science, theory and experiment compliment one another.

The experiences of the Civil War and of the Commonwealth showed that disputed knowledge led to civil strife. It did not seem at all clear that any form of knowledge could produce social order. Yet this is what the experimenters claimed. Hobbes' answer to the problem of civil strife seemed to be an undivided state under a strong leader answerable only to God. It was Newton who first used experimental facts to describe a universe of fixed and immutable physical laws, which were taken by later English writers as symbolic of an ordered society of the King and Parliament.

6 Selected Bibliography

- The standard histories of Boyle's role in the development of science include the following:— A. R. Hall, "From Galileo to Newton", Collins, London, 1983; J. B. Conant, "On Understanding Science", Oxford University Press, Oxford, 1947; T. Sprat, "The History of the Royal Society", Washington University Press, St. Louis, 1959; T. L. More, "The Life and Works of the Honourable Robert Boyle", Oxford University Press, London, 1944.
- One of the most successful re-examinations of the debate between Boyle and Hobbes may be found in S. Shapin and S. Schaffer, "Leviathan and the Air-Pump", Princeton University Press, Princeton, 1985. This book attempts an analysis of the nature of experiment from the position of a

questioning outsider, and offers a charitable interpretation of Hobbes's point of view. It also contains a translation of Hobbes' *Dialogus Physicus de Natura Aeris* and *Dialogus Physicus*.

- For a very readable account of Boyle and the vacuum see R. Wallsgrove, "Selling Science in the 17th Century", *New Scientist*, 24/31 December 1987, p. 55.
- A history of the vacuum is given in T. H. Boyer, *Scientific American*, August 1985, p. 56. Again, readable and non-technical.