

# THE IMPACT OF THE SCIENTIFIC REVOLUTION: A BRIEF HISTORY OF THE EXPERIMENTAL METHOD IN THE 17TH CENTURY\*

Jo Kent

This work is produced by The Connexions Project and licensed under the  
Creative Commons Attribution License <sup>†</sup>

Lauren Ames, Jo Kent, Amneet Gulati, Adam Purtee

Faculty Sponsor: Christopher Kelty, Rice University Department of Anthropology

The Impact of the Scientific Revolution: A Brief History of the Experimental Method in the 17th Century

The American statesman Adlai Stevenson once said, America “can chart our future clearly and wisely only when we know the path which has led to the present.” <sup>1</sup>This is clearly true in the field of science and research. Today, as scientists experiment with nanotechnology and venture into a wide variety of new scientific disciplines, it remains important to take a look back to the origins of scientific discovery and understand some of the events that have shaped the world of science, and, more importantly, to realize how science behaves as an evolving process.

## 1 Introduction

The beginning of the seventeenth century is known as the “scientific revolution” for the drastic changes evidenced in the European approach to science during that period. The word “revolution” connotes a period of turmoil and social upheaval where ideas about the world change severely and a completely new era of academic thought is ushered in. This term, therefore, describes quite accurately what took place in the scientific community following the sixteenth century. During the scientific revolution, medieval scientific philosophy was abandoned in favor of the new methods proposed by Bacon, Galileo, Descartes, and Newton; the importance of experimentation to the scientific method was reaffirmed; the importance of God to science was for the most part invalidated, and the pursuit of science itself (rather than philosophy) gained validity on its own terms. The change to the medieval idea of science occurred for four reasons: (1) seventeenth century scientists and philosophers were able to collaborate with members of the mathematical and astronomical communities to effect advances in all fields; (2) scientists realized the inadequacy of medieval experimental methods for their work and so felt the need to devise new methods (some of which we use today); (3) academics had access to a legacy of European, Greek, and Middle Eastern scientific philosophy they could use as a starting point (either by disproving or building on the theorems); and (4) groups like the British Royal Society helped validate science as a field by providing an outlet for the publication of scientists’ work.

---

\*Version 1.1: Jan 10, 2006 1:26 pm US/Central

<sup>†</sup><http://creativecommons.org/licenses/by/2.0/>

<sup>1</sup>Applebaum, xi.

These changes were not immediate, nor did they directly create the experimental method used today, but they did represent a step toward Enlightenment thinking (with an emphasis on reason) that was revolutionary for the time. Assessment of the state of science before the scientific revolution, examination of the differences in the experimental methods utilized by different “scientists” during the seventeenth century, and exploration into how advances made during the scientific revolution affected the scientific method used in science today will provide an idea of how revolutionary the breakthroughs of the seventeenth century really were and what impact they’ve had.

## 2 Science and Philosophy Before the Revolution

In immediate contrast to modern times, only a few of Europe’s academics at the beginning of the scientific revolution and the end of the sixteenth century considered themselves to be “scientists.” The words “natural philosopher” carried much more academic clout and so the majority of the research on scientific theory was conducted not in the scientific realm per se, but in philosophy, where “scientific methods” like empiricism and teleology were promoted widely. In the 17th century, empiricism and teleology existed as remnants of medieval thought that were utilized by philosophers such as William of Ockham, an empiricist (d. 1349), Robert Boyle (Hall, p 172), a 17th century chemist, teleologist and mechanist, and by the proponents of Plato and Aristotle (1st century teleologists and abstractionists). Both empiricism, as the theory that reality consists solely of what one physically experiences, and teleology, as the idea that phenomena exist only because they have a purpose (i.e. because God wills them to be so), generally negated the necessity of fact-gathering, hypothesis writing, and controlled experimentation that became such an integral part of modern chemistry and biology at the beginning of the 17th century. In other words, the study of science before the scientific revolution was so concentrated on philosophy (such as Aristotle’s conception of “ideas” as ultimate truths) as to preclude the development of a scientific method that would necessitate the creation of an informed hypothesis to be tested. Certain medieval philosophers, however, such as Roger Bacon (1214-1294; no relation to Francis), did emphasize the necessity of controlled experimentation in coming to a theoretical conclusion, but they were few and far between, and generally failed to correctly use the experimental method in practice. For example, author Hall wrote that “Bacon [and other advocates were] guilty of misstatements of fact which the most trifling experiment would have corrected” (Hall, p 163).

## 3 The Advent of the Scientific Revolution – 17th Century

A. R. Hall, in his book *The Scientific Revolution 1500-1800*, made the observation that a main point dividing scientific thought in the seventeenth century from that of the ancient Greeks and medieval Europeans was the choice of questions each group sought to answer through their methods of research or observation.<sup>2</sup> He argued that the first group, that of Copernicus and da Vinci (15th and 16th centuries), focused more on questions of “how can we demonstrate that...” or “how may it be proved that...” that aimed to prove a defined hypothesis true or false, while the second group (that of 17th century chemists and physiologists) emphasized questions phrased as “what is the relationship between...” or “what are the facts bearing upon...” that necessitated fact-finding before a concrete hypothesis could be formulated. The most important point to remember here is that both the questions posed in the 15th century and those of the 17th century form part of the definition of a complete modern “experimental method” – the first type of question cannot stand alone. A concrete hypothesis (question 1) must be accompanied by sufficient, independently verifiable observations (question 2) in order for the scientist to make a vague inference (a form of hypothesis) that can then be tested with a controlled experiment. The way the scientist/philosopher comes by this “vague inference” that will form a concrete hypothesis differs, and these differences can be described as the scientists’ different approaches toward an “experimental method.” The following portion of the module will give an idea of the types of experimental methods promoted by 17th century scientists as well as their impact on the standard experimental method utilized and accepted by chemists, biologists, and physicists today.

---

<sup>2</sup>Hall, p 164

## 4 Case Studies of Scientists and Their “Experimental Methods”

Francis Bacon (1561-1626): Bacon represents a first step away from sixteenth century thinking, in that he denied the validity of empiricism (see introduction) and preferred inductive reasoning (the method of deriving a general “truth” from observation of certain similar facts and principles) to the Aristotelian method of deductive reasoning (the method of using general principles to explain a specific instance, where the particular phenomena is explained through its relation to a “universal truth”). Moreover, like Roger Bacon of the 13th century, Francis Bacon argued that the use of empiricism alone is insufficient, and thus emphasized the necessity of fact-gathering as a first step in the scientific method, which could then be followed by carefully recorded and controlled (unbiased) experimentation. Bacon largely differed from his sixteenth century counterparts in his insistence that experimentation should not be conducted to simply “see what happens” but “as a way of answering specific questions.” Moreover, he believed, as did many of his contemporaries, that a main purpose of science was the betterment of human society and that experimentation should be applied to hard, real situations rather than to Aristotelian abstract ideas. His experimental method of fact-gathering largely influenced advances in chemistry and biology through the 18th century.<sup>3</sup>

Galileo Galilei (1564-1642): Galileo’s experimental method contrasted with that of Bacon in that he believed that the purpose of experimentation should not simply be a means of getting information or of eliminating ignorance, but a means of testing a theory and of testing the success of the very “testing method.” Galileo argued that phenomena should be interpreted mechanically, meaning that because every phenomenon results from a combination of the most basic phenomena and universal axioms, if one applies the many proven theorems to the larger phenomenon, one can accurately explain why a certain phenomenon occurs the way it does. In other words, he argued that “an explanation of a scientific problem is truly begun when it is reduced to its basic terms of matter and motion,” because only the most basic events occur because of one axiom.

For example, one can demonstrate the concept of “acceleration” in the laboratory with a ball and a slanted board, but to fully explain the idea using Galileo’s reasoning, one would have to utilize the concepts of many different disciplines: the physics-based concepts of time and distance, the idea of gravity, force, and mass, or even the chemical composition of the element that is accelerating, all of which must be individually broken down to their smallest elements in order for a scientist to fully understand the item as a whole. This “mechanic” or “systemic” approach, while necessitating a mixture of elements from different disciplines, also partially removed the burden of fact-gathering emphasized by Bacon. In other words, through Galileo’s method, one would not observe the phenomenon as a whole, but rather as a construct or system of many existing principles that must be tested together, and so gathering facts about the performance of the phenomenon in one situation may not truly lead to an informed observation of how the phenomenon would occur in a perfect circumstance, when all laws of matter and motion come into play. Galileo’s abstraction of everything concerning the phenomenon except the universal element (e.g. matter or motion) contrasted greatly with Bacon’s inductive reasoning, but also influenced the work of Descartes, who would later emphasize the importance of simplification of phenomena in mathematical terms. Galileo’s experimental method aided advances in chemistry and biology by allowing biologists to explain the work of a muscle or any body function using existing ideas of motion, matter, energy, and other basic principles.

René Descartes (1596-1650): Descartes disagreed with Galileo’s and Bacon’s experimental methods because he believed that one could only:

“(1) Accept nothing as true that is not self-evident. (2) Divide problems into their simplest parts. (3) Solve problems by proceeding from simple to complex. (4) Recheck the reasoning.”<sup>4</sup> That these “4 laws of reasoning” followed from Descartes’ ideas on mathematics (he invented derivative and integral calculus in order to better explain natural law) gives the impression that Descartes, like many 17th century philosophers, were using advances in disciplines outside philosophy and science to enrich scientific theory. Additionally, the laws set forth by Descartes promote the idea that he trusted only the fruits of human logic, not the results of physical experimentation, because he believed that humans can only definitely know that “they

<sup>3</sup> Hall, p 166, 167

<sup>4</sup> <http://www.hfac.uh.edu/gbrown/philosophers/leibniz/BritannicaPages/Descartes/Descartes.html>

think therefore they are.” Thus, according to Descartes’s logic, we must doubt what we perceive physically (physical experimentation is imperfect) because our bodies are external to the mind (our only source of truth, as given by God). <sup>5</sup>Even though Descartes denounced Baconian reasoning and medieval empiricism as shallow and imperfect, Descartes did believe that conclusions could come about through acceptance of a centrifugal system, in which one could work outwards from the certainty of existence of mind and God to find universal truths or laws that could be detected by reason. <sup>6</sup>It was to this aim that Descartes penned the above “4 laws of reasoning” – to eliminate unnecessary pollution of almost mathematically exact human reason.

Robert Boyle (1627-1691):

Boyle is an interesting case among the 17th century natural philosophers, in that he continued to use medieval teleology as well as 17th century Galilean mechanism and Baconian induction to explain events. Even though he made progress in the field of chemistry through Baconian experimentation (fact-finding followed by controlled experimentation), he remained drawn to teleological explanations for scientific phenomena. For example, Boyle believed that because “God established rules of motion and the corporeal order – laws of nature,” phenomena must exist to serve a certain purpose within that established order. Boyle used this idea as an explanation for how the “geometrical arrangement of the atoms defined the chemical characteristics of the substance.” <sup>7</sup>Overall, Boyle’s attachment to teleology was not so strange in the 17th century because of Descartes’ appeal to a higher being as the source of perfection in logic.

Hooke (1635-1703):

Hooke, the Royal Society’s first Curator of Experiments from 1662-1677, considered science as way of improving society. This was in contrast to medieval thought, where science and philosophy were done for knowledge’s sake alone and ideas were tested just to see if it could be done. An experimentalist who followed the Baconian tradition, Hooke agreed with Bacon’s idea that “history of nature and the arts” was the basis of science. <sup>8</sup>He was also a leader in publicizing microscopy (not discovering, it had been discovered 30 years prior to his *Micrographia*).

Sir Isaac Newton (1643-1747):

Newton invented a method that approached science systematically. He composed a set of four rules for scientific reasoning. Stated in the *Principia*, Newton’s four way framework was: “(1) Admit no more causes of natural things such as are both true and sufficient to explain their appearances, (2) The same natural effects must be assigned to the same causes, (3) Qualities of bodies are to be esteemed as universal, and (4) Propositions deduced from observation of phenomena should be viewed as accurate until other phenomena contradict them.” <sup>9</sup>His analytical method was a critical improvement upon the more abstract approach of Aristotle, mostly because his laws lent themselves well to experimentation with mathematical physics, whose conclusions “could then be confirmed by direct observation.” Newton also refined Galileo’s experimental method by creating the contemporary “compositional method of experimentation” that consisted in making experiments and observations, followed by inducted conclusions that could only be overturned by the realization of other, more substantiated truths. <sup>10</sup>Essentially, through his physical and mathematical approach to experimental design, Newton established a clear distinction between “natural philosophy” and “physical science.”

All of these natural philosophers built upon the work of their contemporaries, and this collaboration became even simpler with the establishment of professional societies for scientists that published journals and provided forums for scientific discussion. The next section discusses the impact of these societies, especially the British Royal Society.

---

<sup>5</sup>Hall, p 178

<sup>6</sup>Hall, p 179

<sup>7</sup><http://www.rod.beavon.clara.net/leonardo.htm>

<sup>8</sup>Hellyer, p 36

<sup>9</sup>Set of four rules, <http://scienceworld.wolfram.com/biography/Newton.html> (<<http://scienceworld.wolfram.com/biography/Newton.html>>):

<sup>10</sup>Ibid website.

## 5 The Role of the Royal Society

Along with the development of science as a discipline independent from philosophy, organizations of scholars began to emerge as centers of thought and intellectual exchange. Arguably the most influential of these was the Royal Society of London for the Improvement of Natural Knowledge (from official website <http://www.royalsoc.ac.uk/page.asp?id=2176><sup>11</sup>), which was established in 1660 with Robert Hooke as the first Curator of Experiments. Commonly known as the Royal Society, the establishment of this organization was closely connected with the development of the history of science from the seventeenth century onwards. <sup>12</sup>The origins of the Royal Society grew out of a group of natural philosophers (later known as "scientists") who began meeting in the mid-1640s in order to debate the new ideas of Francis Bacon. The Society met weekly to witness experiments and discuss what we would now call scientific topics. A common theme was how they could learn about the world through experimental investigation.

The academy became an indispensable part of the development of modern science because in addition to fostering discussing among scientists, the Royal Academy became the de facto academy for scientific study in Europe. Accomplished scientists served as Royal Academy Fellows and exchanged ideas both casually and formally through the publication of articles and findings. These scholars, especially Francis Bacon, served as an important resource for the justification of the new fact-gathering, experiment-based experimental method as well as for the validation of "modern (17th century) science." Moreover, the work they published through the society helped gain credibility for the society and for science as a discipline. For example, scholars such as Robert Boyle published significant scientific findings in its unofficial journal *Philosophical Transactions* (Dear, p 140). Other famous scientists that joined the society included Robert Boyle, Isaac Newton and William Petty, all of whom benefited from academic collaboration within the society and from increased publicity generated by their published works.

Dedicated to the free exchange of scientific information, the Royal Society of London - and later, its counterparts throughout Europe such as The Hague and the Academy of Sciences in Paris - proved crucial to the discussion and design of modern science and the experimental method. Although the Royal Society was a governmentally established body, it acted independently as a body dedicated to research and scientific discovery - that is to say, to improving knowledge and integrating all kinds of scientific research into a coherent system. With such a central artery for scientific progress, scientists were able to more quickly and fiercely support and promote their new ideas about the world.

## 6 Conclusion

The defining feature of the scientific revolution lies in how much scientific thought changed during a period of only a century, and in how quickly differing thoughts of different natural philosophers condensed to form a cohesive experimental method that chemists, biologists, and physicists can easily utilize today. The modern experimental method incorporates Francis Bacon's focus on use of controlled experiments and inductive reasoning, Descartes' focus on hypothesis, logic, and reason, Galileo's emphasis on incorporation of established laws from all disciplines (math, astronomy, chemistry, biology, physics) in coming to a conclusion through mechanism, and Newton's method of composition, with each successive method strengthening the validity of the next. Essentially, the scientific revolution occurred in one quick bound and the advances made from the 17th century onward appear as little skips in comparison.

However, one must keep in mind that although the Greeks and the philosophers of the 17th century invented and began to perfect the experimental method, their outcomes in their experiments were often flawed because they didn't follow their own advice. Even philosophers like Francis Bacon, the main promoter of fact-gathering and controlled experimentation failed at some point in time to control their experiments or use peer review, or used too much inference/logic and too little mathematic proof/experiment. In short, scientists today must learn from the mistakes of the 17th century philosophers like Galileo who wrote so eloquently about the necessity of a successful scientific method but didn't execute it correctly or failed to

---

<sup>11</sup> <http://www.royalsoc.ac.uk/page.asp?id=2176>

<sup>12</sup> 11Brief History of the Royal Society of London : <http://www.royalsoc.ac.uk/page.asp?id=2176>

recognize the importance of pursuing scientific progress not simply for theoretical excellence, but for how it can improve the human condition.

The lesson to take from the history of the scientific revolution is that the ideas of the 17th century philosophers have the most impact in the context of the progress they made as an academic whole – as singular scientists, they became more prone to faulty logic and uncontrolled experimentation. For instance, non-scientific reasoning such as teleology continued to affect genius philosophers and scientists such as Descartes and Boyle, and today scientists are faced with the problem of intelligent design (teleology) being taught as the equivalent of peer-reviewed, substantiated evolutionary theory. Overall, modern scientists remain just as prone to the same problems as the 17th century philosophers and therefore might consider looking toward the legacy of the successes of the scientific revolution against the backward medieval philosophy for guidance.

### 6.1 Works Cited

1. "About the Society." The Royal Society 2005. The Royal Society. 15 Nov. 2005 <<http://www.royalsoc.ac.uk/page.asp?id=>
2. Dear, Peter. *Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500-1700*. Princeton: Princeton University Press, 2005.
3. Francis Bacon. Farlex, Inc. *The Free Dictionary* 16 Nov. 2005 <<http://img.tfd.com/authors/bacon.jpg>>.
4. Galileo Galilei. NASA. 16 Nov. 2005 <<http://antwrp.gsfc.nasa.gov/apod/ap980913.html>>.
5. Hall, A R. *The Scientific Revolution 1500-1800: The formation of the Modern Scientific Attitude*. London and Colchester: Longmans, Green and Co, 1954.
6. Hellyer, Marcus. *The Scientific Revolution*. Oxford: Blackwell Publishing Ltd, 2003.
7. Isaac Newton. Université de Nantes. Sciences - Université de Nantes. 16 Nov. 2005 <<http://www.sciences.univ-nantes.fr/physique/enseignement/tp/hist/newton.jpg>>.
8. René Descartes Free Online Library by Farlex. 16 Nov. 2005 <<http://descartes.thefreelibrary.com/>>.
9. "Robert Boyle." 15 Nov. 2005 <<http://dbhs.wvusd.k12.ca.us/webdocs/GasLaw/Gas-Boyle-Data.html>>.
10. Robert Hooke. NNDB. 15 Nov. 2005 <<http://www.nndb.com/people/356/000087095/robert-hooke-1.jpg>>.