new dictionary of the history of ideas

maryanne cline horowitz, editor in chief

volume 2

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Robert C. Solomon

EXPERIMENT. This entry traces the life of experiment from its emergence in the early seventeenth century to its transformation to a collective activity after World War II. The topics discussed include the rise of experimental philosophy and its institutional expression in the new scientific societies of the seventeenth century; the spread and character of experimentation in the eighteenth century; the quest for precision and the rise of laboratories in the nineteenth century; and the emergence of a new form a collective experimental life after World War II.

The Emergence of Experiment

The birth of experiment has been the subject of considerable debate among historians of early modern science. The received view is that experimentation emerged in the seventeenth century as part of an era of radical discontinuity in the methods and practices of investigating nature. Among the natural philosophers who developed and practiced experimentation, some of the most eminent were Francis Bacon (1561–1626), Galileo Galilei (1564–1642), Robert Boyle (1627–1691), and Isaac Newton (1642–1727). There have been challenges to this view, most notably by A. C. Crombie, who suggested in the early 1950s that the experimental method originated in the late medieval period. In the thirteenth and fourteenth centuries medieval scholars reflected in a systematic fashion on experiment as a method for the acquisition of natural knowledge. Furthermore, experiments had been performed, mostly in the context of mathematical sciences such as optics, well before the seventeenth century. Other historians have pointed out that experimentation had a prehistory in craft traditions and in occult practices, such as alchemy and natural magic. The practical skills of craftsmen and artisans and the experimental practices of alchemists contributed significantly to the emergence of experimental science in the seventeenth century.

It remains the case, however, that *systematic* and *extensive* attempts to understand and manipulate nature by means of experiment did not take place before the seventeenth century. Before the scientific revolution, the dominant means of acquiring information about the natural world was unaided observation. That was in line with Aristotelian natural philosophy, which attributed a prominent epistemological role to quotidian (common, everyday) experience. In the seventeenth century that role was gradually taken over by experiment—the active "interrogation" of nature—which was carried out by intervening in nature's workings and by manipulating its forces. In the process, unaided observation gave way to observation by means of instruments (such as the barometer, thermometer, air pump, and microscope), which enabled natural philosophers to measure and explore nature under controlled and, sometimes, artificial conditions. Those instruments considerably extended the range of phenomena that was accessible to the senses.

Two Experimental Traditions: Classical and Baconian

To understand the rise of experiment, it would be helpful to recall a significant distinction, drawn by Thomas S. Kuhn, between two different traditions in the development of the sciences. The first tradition, the classical sciences (mathematics, astronomy, harmonics, optics, and statics), had been well developed since antiquity. Those sciences were radically transformed in the sixteenth and seventeenth centuries. In that transformation, however, experimentation played a minor role. The second tradition, the Baconian sciences that emerged in the seventeenth century, investigated electric, magnetic, chemical, and heat phenomena. Experimentation was instrumental in the emergence and development of this tradition.

Furthermore, the mode of experimentation was different in the two traditions. In the classical tradition experiments were guided by theory, involved idealization, and were, often, not clearly distinguished from thought experiments. Their outcomes were presented in the form of universal, lawlike generalizations. In the Baconian tradition, on the other hand, experiments had an exploratory character and were carried out with an eye to the local, contingent conditions that gave rise to the observed phenomena. Detailed circumstantial information about those phenomena was included in the written reports of the experiments, whose aim was to establish particular "matters of fact." Those phenomena were created or measured by some of the new instruments that were invented in the seventeenth century (such as thermometers, air pumps, and electrostatic generators).

These two traditions started to merge only toward the end of the eighteenth century in France, where Pierre-Simon Laplace (1749–1827) and his followers attempted to develop mathematical theories of the phenomena investigated by the Baconian tradition.

Galileo Galilei

The extent to which Galileo did experiments has been a controversial issue. The dominant view well into the twentieth century was that Galileo was among the first "scientists" who experimented extensively and developed his theories on the basis of his experiments. In the 1930s Alexandre Koyré disputed that view and argued strenuously that Galileo's engagement with experiment was minimal. Galileo, according to Koyré, was a Platonist philosopher, who, for the most part, did not perform real experiments and reached his theoretical conclusions relying on a priori (deductive) reasoning and thought experiments. A significant reason for Koyré's claim was the excessive accuracy of many of the experimental results that Galileo reported in his published work.

Subsequent scholars have disputed some of Koyré's claims. Starting in the early 1960s, Thomas B. Settle and Stillman Drake, among others, drawing on a wider range of Galileo's manuscripts than was available to Koyré, managed to replicate several of Galileo's experiments on motion and obtained results that were close to the ones that he reported. In the wake of these studies, a consensus has developed among Galileo scholars that he was an ingenious experimenter, who designed and carried out a variety of experiments. Furthermore, experimentation and measurement were essential to Galileo's widely known discoveries, the law of free fall and the parabolic trajectories of projectiles. Galileo's image as the preeminent experimental philosopher has been reinstated.

One of the problems faced by experimental philosophers was how to legitimize experimentation as a means of acquiring knowledge of nature. Common experience could function as an unproblematic foundation for natural philosophy because of its familiarity and accessibility to everyone. The novel phenomena discovered by means of experiment, on the other hand, were neither familiar nor accessible to all. Two issues had to be tackled: first, the veracity of experimental results had to be attested. Second, particular results obtained under local, contingent circumstances had to acquire the status of general truths about nature.

An instance of how Galileo attempted to address these issues is provided by his investigations of free fall, which were carried out in the early years of the seventeenth century and published many years later in his *Two New Sciences* (1638). In that work he did not provide any circumstantial information about the particular experiments he had performed with rolling balls on incline planes. Furthermore, he did not report the specific results he had obtained. Rather he gave a generic description of the experimental setup and pointed out that the results conformed repeatedly ("a full hundred times") to what he had anticipated.

Experimental philosophers in the Baconian tradition also faced the problem of legitimizing experiment, but they confronted it differently. This tradition is the topic of the next two sections.

The Baconian Program and Its Institutional Expression

Francis Bacon was one of the most eloquent advocates of the new experimental method. In *The New Organon* (1620), a logical treatise that was meant to supersede Aristotle's *Organon,* he stressed the importance of inductive reasoning for the investigation of nature. Bacon argued, however, that the starting point of inductive reasoning should not be the information obtained by the unaided senses, because it is limited or even deceptive. Rather, the senses should be assisted by "instances and experiments fit and apposite" (p. 53). The knowledge thus acquired about natural phenomena would then be codified in natural or experimental "histories." Furthermore, the point of natural knowledge was to give humans the power to intervene in natural processes for their own benefit. The understanding of nature and its manipulation were inextricably tied: "Nature to be commanded must be obeyed" (p. 39).

Another important aspect of Bacon's program was his emphasis on the social nature of the knowledge-seeking enterprise. In his utopian *New Atlantis* (1627) he suggested that investigation of the natural world should be a collaborative pursuit, carried out in special institutions. Bacon's vision inspired the founding of the Royal Society of London (1660) and the Académie Royale des Sciences in Paris (1666). Christiaan Huygens (1629–1695), a prominent member of the Paris Academy, contended that "the principal occupation of the Assembly and the most useful must be, in my opinion, to work in natural history somewhat in the manner suggested by" Bacon (Dear, p. 116). The primary aim of the Royal Society was also Baconian, namely the advancement of experimental knowledge. As one of its statutes reads, "The business of the Society in their Ordinary Meetings shall be to order, take account, consider, and discourse of philosophical experiments and observations" (Hall, p. 1).

Yet, the experiments that were carried out and discussed under the auspices of the Royal Society had a different aim than that envisaged by Bacon. Bacon viewed experiment as a means for discovering general truths about nature. Experimental outcomes were not just particular events, but instances of universal generalizations. The kind of experimentation practiced in the Royal Society, on the other hand, aimed at establishing particular facts. The presentations of experiments that were published in *The Philosophical Transactions of the Royal Society* were written in a specific manner, containing detailed and circumstantial information about the experiments in question. The point of this rhetorical strategy was to create the illusion of "virtual witnessing" and thereby persuade the intended audience of the veracity of the results obtained. This fascination with particular "matters of fact" is evident in the work of Robert Boyle.

The Boyle–Hobbes Dispute

Boyle was among the more eminent followers of the Baconian program. Many of the issues and difficulties faced by that program can be seen in his controversy with the philosopher Thomas Hobbes (1588–1679) over the character of knowledge in natural philosophy. For Boyle knowledge of nature should be descriptive and based on consensus. The aim of experimental inquiry had to be the establishment of matters of fact and not the discovery of their underlying causes. Hobbes, on the other hand, argued that knowledge should be demonstrative, causal, and necessary. Thus, the experimental production of artificial effects could not lead to true knowledge, because the inference from effect to cause is always hypothetical.

In the course of their controversy Hobbes and Boyle debated the implications of the latter's experiments with the air pump. By means of that instrument, Boyle had managed to create a vacuum. In defending his results, he claimed that his experiments were publicly performed and could be replicated at will. Hobbes disputed those claims and emphasized the artificiality of Boyle's results. Hobbes's critique was an instance of a more general skepticism toward scientific instruments, some of which created phenomena that did not exist in nature. For that reason, their legitimacy was contested. At issue was whether they revealed natural processes or produced artifacts and, thereby, distorted nature.

According to Steven Shapin and Simon Schaffer, the significance of the Boyle–Hobbes debate extended far beyond natural philosophy. Shapin and Schaffer made a fascinating case that the eventual establishment of the experimental "form of life" implicated wider social and religious issues. In particular, they argued that Boyle's experimental program was in tune with the need for order and consensus in Restoration England. The general validity of this thesis, however, is questionable. By the end of the seventeenth century the "experimental philosophy" had spread throughout continental Europe, where the social and religious conditions differed significantly from those in England.

The rise of experimental philosophy gradually undermined the identification of science with demonstratively certain knowledge. Experimental results came to be seen as only "morally" certain—that is, certain for all practical purposes. Explanatory hypotheses, on the other hand, came to be regarded as merely probable. The quest for certainty, though, was never entirely abandoned, as is testified to by Isaac Newton's work.

Newton as an Experimental Philosopher

Newton famously claimed that hypotheses are not admissible in natural philosophy. The proper method of inference was deduction from the phenomena:

> whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy, particular propositions are inferred from the phenomena, and afterwards rendered general by induction. (p. 547)

As several historians and philosophers of science have pointed out, however, there was a gap between Newton's methodological pronouncements and his actual scientific work. Newton himself frequently made use of hypotheses. His various deductions from the phenomena relied on various theoretical assumptions, and thus the "deduced" propositions were not, strictly speaking, deduced from the phenomena.

Newton was a prominent member of the Royal Society, and its president from 1703 until his death. His main experimental contributions concerned the mathematical science of optics. In his experimental work Newton attempted to come up with "crucial experiments" that would enable him to choose among competing hypotheses of the phenomena under investigation. Robert Hooke (1635–1703), in his *Micrographia* (1665), coined the term *experimentum crucis.*

During the 1660s Newton carried out a series of experiments on light, using a familiar instrument, the prism. Based on those experiments, he concluded that light was a composite entity, consisting of distinct rays, whose refractive properties depended on their color. Newton reported the experiments he had carried out in a paper that was published in the *Philosophical Transactions of the Royal Society* in 1672, where he adopted the customary presentation style of the Royal Society. That paper got him involved in a prolonged controversy with Hooke, who was then the curator of experiments in the Royal Society, a controversy that lasted until 1678. Hooke did not dispute the results of Newton's experiments, which he managed to reproduce. Rather he challenged Newton's inferences from those results and, in particular, Newton's conclusions on the composition of light.

After that controversy Newton remained silent on optics until Hooke's death. He then published his experimental and theoretical investigations on light in *Opticks* (1704), a book that was written in the vernacular without the use of mathematics. In that book Newton developed a corpuscular theory of light, which encountered opposition in continental Europe. Newton took advantage of his presidency of the Royal Society and his ever-growing power to face that opposition. He directed the work of the official experimentalists of the Royal Society, Francis Hauksbee (c. 1666–1713) and John Desaguliers (1683–1744), who effectively promoted the Newtonian worldview through their experimental researches, public lecturing, and textbook writing.

The Spread of Experimental Philosophy in the Eighteenth Century

The fortunes of experimentation in the eighteenth century were closely linked with the spread of Newtonianism. *Opticks* functioned as a model of a developing experimental tradition. Prominent representatives of that tradition were the Dutch Newtonians Willem Jacob 's Gravesande (1688–1742) and Petrus van Musschenbroek (1692–1761), who wrote very influential books, whose main function was educational.

In the first half of the eighteenth century there was still no clear distinction between professional and amateur experimental philosophers. It was customary for experimentalists to obtain part of their income by performing striking electrical or optical experiments in public. This aspect of experimentation enlarged the audience for natural philosophy. However, it annoyed some university professors, who observed with dismay that the popularity of experiments was based on their potential for entertainment.

Experimentation for most of the eighteenth century was predominantly empirical and qualitative, without systematic guidance by mathematically formulated theories. Various phenomena (electrical, thermal, and chemical) were explored experimentally, on the assumption that they were manifestations of hidden imponderable entities (electric fluids, caloric, and phlogiston, respectively). The invention of new instruments (for example, the Leyden jar), and the improvement of existing ones (such as the thermometer), played a seminal role in investigating these phenomena. Earlier in the century the acquisition of instruments was the responsibility of well-off professors of experimental physics, who collected and stored them in "physical cabinets." In the second half of the century the task of establishing and maintaining collections of instruments was gradually taken over by universities and scientific academies.

Toward the end of the century, and especially in France, there was a shift toward the quantification of experimental physics. New quantifiable concepts were introduced, such as charge and heat capacity, which facilitated this shift and led to the construction of mathematical theories of static electricity and heat. Furthermore, precise measurements were systematically carried out and meticulously reported in numerical tables. Precision measurement gradually became a central preoccupation of experimental physics.

The Nineteenth Century

Experiment continued to be a significant driving force in the development of the physical sciences in the first half of the nineteenth century. The experimental discovery of novel phenomena (for example, electromagnetism) and the precise measurement of physical parameters (such as the mechanical equivalent of heat) were instrumental in the development of electromagnetic theory and thermodynamics. The articulation of these theories in the second half of the nineteenth century guided, in turn, the further experimental exploration of thermal and electromagnetic phenomena. In the process the mathematical and the experimental traditions of physical science merged.

By the end of the nineteenth century, precision in measurement had become almost an obsession among physicists, who believed that it held the key to the further development and eventual closure of their discipline. In the words of James Clerk Maxwell (1831–1879),

> This characteristic of modern experiments—that they consist principally of measurements, —is so prominent, that the opinion seems to have got abroad, that in a few years all the great physical constants will have been approximately estimated, and that the only occupation which will then be left to men of science will be to carry on these measurements to another place of decimals. (Badash, p. 50)

Several experimental developments (such as X rays, radioactivity, the photoelectric effect, and blackbody radiation) at the end of the nineteenth century put off the end of physics. Under the weight of these and other experimentally probed phenomena, the edifice of classical physics would crumble.

The nineteenth century was also an important period for the establishment of a new physical and institutional space devoted to experimentation, the academic laboratory. With some exceptions, laboratories had previously been private places, usually located in the houses of wealthy experimentalists. In the 1870s and 1880s the founding of new university laboratories (including the Cavendish Laboratory at Cambridge, the Clarendon Laboratory at Oxford, the Jefferson Laboratory at Harvard) and new institutes (for example, the Physikalisch-Technische Reichsanstalt near Berlin) devoted to experimental research marked a new era for experimentation, which became an essential element of both research and teaching in the physical sciences.

Coda: Experimentation in the Twentieth Century

In the twentieth century perhaps the most significant break with respect to the character of experimentation came via World War II. The Manhattan Project for the development of the atomic bomb marked the beginning of experimentation on an enormous industrial scale. After the war a new form of experimental life, so-called big science, developed. Laboratories in certain areas of physics came to resemble huge factories, where hundreds, or even thousands, of scientists collaborated to design and carry out extremely expensive and time-consuming experimental projects. In these fields, tabletop experiments by a few experimentalists became a thing of the past.

See also ***Empiricism; Science; Science, History of.***

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Theodore Arabatzis

EXPRESSIONISM. Of all the "isms" in the early twentieth century, Expressionism is one of the most elusive and difficult to define. Whereas, on the one hand, Expressionism has been said to reveal its "universal character," abandoning all theories that imply a narrow, exclusive nationalistic attitude, on the other, it has been considered a "specific and familiar constant in German art for hundreds of years" (Vogt, p. 16). Scholarship has attempted to address the problematic range of the term and the contradictory emphases in its historiography. Although Expressionism did not constitute a cohesive movement or homogenous style, attention has been directed to the origins of the word and its meanings in critical discourse as well as to the contingent issues of art, society, and politics framing Expressionist avant-garde culture. Spurred on by an increasing overlap of the humanities with social, cultural, and gender studies, recent investigations reject notions of a transcendent *Zeitgeist* in focusing on Expressionism's interface with the public sphere.

Expressionism in Germany flourished initially in the visual arts, encompassing the formation of Künstlergruppe Brücke (Artists' Group Bridge) in Dresden in 1905 and the Blaue Reiter in Munich in 1911. The notion of the *Doppelbegabung,* or double talent, characterized many artists' experimentation in the different art forms, whether lyric poetry, prose, or drama. The notable precedent for this was the music-dramas of Richard Wagner and the attendant concept of the *Gesamtkunstwerk,* which excited artists' and writers' interests in the union of the arts into a theatrical whole. Performed at the Wiener Kunstschau in 1909, Oskar Kokoschka's (1886–1980) *Mörder, Hoffnung der Frauen* (Murderer, hope of women) is considered one of the first Expressionist plays to involve a high degree of abstraction in the text, *mise en scène,* sound effects, and costume. Comparatively speaking, Reinhard Sorge's (1892–1916) play *Der Bettler* (The beggar), written in 1910, is more discursive, though no less abstracted in relaying the metaphysical stages (*Stationen*) achieved by the chief protagonist, "the Poet" himself (Furness, in Behr and Fanning, p. 163). Hence, by 1914, the concept of Expressionism permeated German metropolitan culture at many levels, gaining momentum during World War I and in the wake of the November Revolution in 1918. However, any attempt to define Expressionism chronologically is as problematic as doing so in terms of style, since its influence was still felt in film after the holding of the first *Neue Sachlichkeit* (New Objectivity) exhibition in Mannheim in 1925.

It is telling that the kernel concept of the "expressive"—the primacy of the creative process at the expense of verisimilitude—became significant in Germany at the height of the Second Empire, corresponding to the reign of the Hohenzollern king of Prussia, Wilhelm II. The period between 1890 and 1914 was characterized by colonial expansion abroad, an unprecedented degree of urbanization and technical transformation at home, and promotion of a hide-bound national public art. Generally speaking, Expressionism grew out of late-nineteenth-century dissatisfaction with academic training and the mass spectacle of state-funded salons, the Munich (1892) and Berlin secessions (1898) withdrawing from such official or professional affiliation. In their exhibitions, the secessions fostered a sense of pluralism and internationalism, maintaining links with the art market and Paris-based Impressionism and Postimpressionism.

Within this shifting ambience between tradition and the modern, the term *Expressionisten* (Expressionists) was initially applied to a selection of French Fauvist and not German artists in the foreword to the catalog of a Berlin Secession exhibition, held in April 1911. Given the largely Impressionist leanings of the Secession, the collective term was a convenient way of signifying the "newest directions" in French art. Here the art of self-expression, or *Ausdruckskunst* as it was articulated in German, involved a degree of expressive intensification and distortion that differed from the mimetic impulse of naturalism and the Impressionist mode of capturing the fleeting nuances of the external world. This aesthetic revolt found theoretical justification in the writing of the art historian Wilhelm Worringer (1881–1965), whose published doctoral thesis *Abstraktion und Einfühlung* (1908, Abstraction and empathy) proposed that stylization, typical of Egyptian, Gothic, or Primitive art, was not the result of lack of skill (*Können*) but was propelled by an insecure psychic relationship with the external world. An impelling "will to form," or *Kunstwollen,* underscored art historical methodology at the time (Jennings, in Donahue, p. 89).

Evidently, the label *Expressionism* was not invented by the artists themselves but abounded in the promotional literature and reviews of current exhibitions. The proliferation of