Scientific Thought: Validation Through Publication via The Transactional Accounts of the Royal Society in the 17th Century

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Thesis

The age of the Internet has transformed scholarly publishing from a closed and highly scrutinized process to a relatively unsupervised and open online affair. Predatory scientific journals have emerged online and solicit contributions from young researchers anxious to publish their work; the plethora of scientific journals has led to confusions over validity within the scientific community. The skepticism necessary for scientific progress has receded leading to a rightful shock whenever a researcher is found to have made fraudulent claims. Standards and perhaps even certain ethical principals that date back to the seventieth century have become questionable in the face of the constant and revolutionary progress of research.[1]

The *Philosophical Transactions* of the Royal Society of London could be considered the earliest scientific periodical. The fellows of the Royal Society of London emerged as the leading scientific society in the English-speaking world due to their adherence to a set of standards proposed by Francis Bacon and implemented by Henry Oldenburg and Robert Boyle among other prominent academy fellows. These standards created a framework for evaluating claims to knowledge about the natural world, aiding both the respected and amateur scientist in their attempts to describe discoveries to the reading public. The *Transactional Accounts of the Royal Society* published periodically and edited by Henry Oldenburg legitimized scientific discoveries in an era in which the criteria for evaluating them had not yet been formalized. The publication and organization of the society served as a model for future royal academies of science. In

[1] Larissa Shamseer, et al. "Potential Predatory and Legitimate Biomedical Journals: Can You Tell the Difference? A Cross-Sectional Comparison." *BMC Medicine*, BioMed Central, 16 Mar. 2017.

order to grasp the significance of the *Philosophical Transactions*, we need to situate that publication within the broader context of the paradigm shift in thought and understanding of the natural world termed 'The Scientific Revolution,' which occurred in Europe during the 16th and 17th centuries.

I. The Scientific Revolution: The Telescope and A New Conception of Method

At the outset of the 17th century, the community of individuals who engaged in speculation and discussion concerning natural philosophy faced a major challenge that ignited a debate about ideology and method. This challenge was due to the invention by a Dutch spectacle maker named Hans Lippershey of the telescope, the first major advancement in observational technology. In 1608, Lippershey presented his invention to the Captain-General of the Dutch republic, Maurice, Prince of Orange, Count of Nassau. It contained a version of glass lenses in which distant things could be viewed as if they were nearby.[2] Through this invention the Captain-General was able to see the clock in the city of Delft, a distance of approximately 7 miles, from a tower located in The Hague. This account was printed and reprinted in France, reaching Venice, the city in which Galileo resided, by the end of the year. Upon reading the account, Galileo gathered the materials and designed his own version of the telescope, but instead of looking at objects on earth, as Maurice had done, he trained the invention on the sun.

After making repeated observations of the sun, Galileo noticed sunspots, which he described in his notes as irregularly shaped and varying from day to day in opacity and location. To describe these sunspots, he made a comparison to earthly clouds or "vapors

[2] Edward G. Rusetow, *The Microscope in the Dutch Republic: The Shaping of Discovery* (Cambridge University Press, 1996) p. 6

raised from the earth and attracted to the sun."[3] Other gentleman scientists believed that these spots were small planets orbiting the sun at a considerable distance and projecting a shadow of sorts. Galileo disagreed. He held that they were "not at all distant from its [i.e., the sun's] surface, but are either contiguous to it or separated by an interval so small as to be quite imperceptible."[4] This interpretation was taken to be a challenge to the accepted Aristotelian natural philosophy on the cosmos, the dominant theory taught at universities through the period of the Renaissance. Religious notions coupled with certain philosophical ideas on the heavens dictated that the sun was immaculate and immutably perfect, so the blemishes observed by Galileo could not be on the solar surface. Galileo made formal calculations of the diameter of the spots that he observed and arrived at conclusions regarding the orbits of planets in the solar system. This was a revolutionary method of investigation. Whereas previously reasoning alone had been sufficient to prove a conclusion, Galileo argued that a priori reasoning could not disprove empirically grounded claims.

Galileo's method inaugurated a major 'paradigm' shift in the study of natural phenomena, to employ the concept coined by the philosopher of science Thomas S. Kuhn in his work on the *Structure of Scientific Revolutions.* Galileo continued to observe the cosmos and became a champion of the heliocentric theory, a cosmology that he defended before the Inquisition tribunal that sentenced him to house arrest.[5] He would spend his last ten years writing and observing the night sky from his home in Florence, Italy. The example that he set inspired others not only to scan the heavens with a telescope but also

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[3] Steven Shapin, *The Scientific Revolution* (University of Chicago Press, 1996). (Kindle Locations 194-195). Kindle Edition.

[4] Shapin, *The Scientific Revolution*. (Kindle Locations 194-195). Kindle Edition.

[5] Thomas Kuhn. *Structure of the Scientific Revolution*. (University of Chicago Press, 2004)

to examine the physical world under the microscope. This break in paradigm called for the formulation or codification of the new method of inquiry. Even before the trial and condemnation of Galileo by the Inquisition, the English philosopher Francis Bacon attempted to provide such a statement on method in his *The New Organon*, a critique of Aristotle's *Organon*, or book on logic, published in 1620.

The Baconian method is inductive. It calls for the use of empirical evidence in the formulation of a conclusion rather than reason alone, religious dogma, or the authority of ancient philosophers. At a time when many scholars were calling for a return to the authority of the ancients and treated natural philosophy as subservient to theology, an empirical approach represented a radical break from the university system. Above all, the inductive method challenged the still powerful influence of Aristotelianism over natural philosophy.

II. The Age of Observation: The Invention of the Microscope

The first account of the second revolutionary scientific instrument in the 17th century, the microscope, came eleven years after the account of the telescope, from which the microscope was derived. The Dutch diplomat Willem Boreel claimed the invention of the microscope for his friend Sacharias Janssen. Boreel described the Jannssen microscope that he viewed in 1619 as constructed with a foot and a half gilded brass tube rising vertically from three dolphin shaped legs.[6] The compound microscope differed from the telescope in that it utilized a system of two convex lenses rather than the combined convex and concave lenses of the telescope. It was the paired convex lenses that made the microscope compact. It could be placed on a table top while also offering

[6] Rusetow, *The Microscope in the Dutch Republi*c. Pg. 4

the viewer a broad field of vision. The nature of the lenses of the Janssen microscope remains unknown. Historians often credit the invention of the compound microscope to Cornelis Drebbel, whose design was sold around the European content. The last account in the archives of the Drebbel microscope reported the device to be an inch in diameter with a tube containing the lenses to be about the length of a travel quill case and constructed of three pieces of gilded brass allowing for the length to be adjusted by the user to derive the best possible image.[7] It would be about 200 years later in the late 19th century that equations to measure focal length and aperture would be derived in the field of optics.

In the 17th century, the user of the microscope had continually to adjust the instrument in order to achieve a clear image. Other microscopes were produced with slight improvements in the quality of the lenses, but such minor improvements did not make the microscopes fundamentally different from the standard Drebbel device. In any case, the new device "accentuated rather the endless and often inexplicable diversity of natural forms and what seemed at times their superfluous and irrepressible abundance."[8] Because the making of a microscope required minimal technical expertise, many amateur scientists, driven by a combination of curiosity and ambition, made use of the new instrument. The result was a plethora of detailed accounts and illustrations of the veins of a leaf or fly wing among other observations. From this plethora of observations came an immediate challenge. How was one to make sense of those observations and categorize them given that "the conceptual resources at hand were usually crude, ill-fitting, or

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[7] *Ibid.*, pg. 11
[8] *Ibid.*, pg. 36

simply unpersuasive"[9] While astronomical discoveries could be grouped within an ever-changing theory of the cosmos, observations of microscopic matter lacked such overarching classification. The lack of an overarching classification system meant that a keen observer had to describe his observation to the scientific community since, "the telescope discovered little for which precedents and analogies did not readily come to mind. Not so in the realm of the microscope."[10] In addition, there was the problem of how to verify an observation made under a microscope. The newly created scientific societies sought to solve that problem.

III. The Scientific Revolution: A Revolution in Method

The new scientific instruments enhanced the power of the human eye to view the astronomical and physical world. There was no consensus, however, on how to verify, much less interpret, the discoveries that the instruments made possible. Robert Boyle championed the idea of the "fact," an element of knowledge that has been solidified and verified. The "matter of fact" would then in turn serve as the foundation for other discoveries and advancements in knowledge. This created a demarcation between knowledge and opinion, with the former grounded in fact and the latter deriving from conjecture or speculation. Boyle and others committed to the experimental method maintained that, "proper philosophical knowledge should be generated through experiment and that the foundations of such knowledge were to be constituted by experimentally produced matters of fact."[11]

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[9] *Ibid*., pg. 3

[10] *Ibid*., pg. 3

[11] Steven Shapin *Leviathan and the Air Pump* (Princeton University Press, 1985). p.22

Experimentally produced matters of fact depended on three technologies: a material technology, literary technology, and a social technology. These tools were not independent but interdependent: they had to be used together in order to establish a fact on which the researcher could depend. The material technology was a scientific instrument, a device that served to enhance perception and allowed for an observation to be clearly drawn or described. The literary technology comprised the language and the physical medium through which observations were conveyed, often in such a way as to restrict the audience to a narrow circle of learned men. And the social technology, hailed by Boyle as paramount in combatting the inherent fallibility of the human being, aimed to "assure others that grounds for their belief were adequate. In that process a multiplication of the witnessing experience was fundamental."[12] In short, before an experiment and observation could produce "a matter of fact," other learned men had to witness them; hence the importance of scientific societies, organizations that could, in some cases, perform the work of validation for their members.

In some cases though not all. Many scientists lived and conducted experiments at a considerable distance from the cities in which the learned societies were located. In those cases, the condition for establishing matters of fact was either that other scientists be able to replicate the same results, or what the historian Steven Shapin has termed "virtual witnessing": "The technology of virtual witnessing involves the production in a reader's mind of such an image of an experimental scene as obviates the necessity for either direct witness or replication."[13] In order to participate in virtual witnessing, one would need to be an expert on the physical world and familiar with the new scientific

[12] *Ibid.*, p. 25
[13] *Ibid.*,p. 60

technologies. Yet even an expert cannot individually certify a matter of fact; only a group of expert natural philosophers can parse out the details of a scientific paper and discuss its credibility.

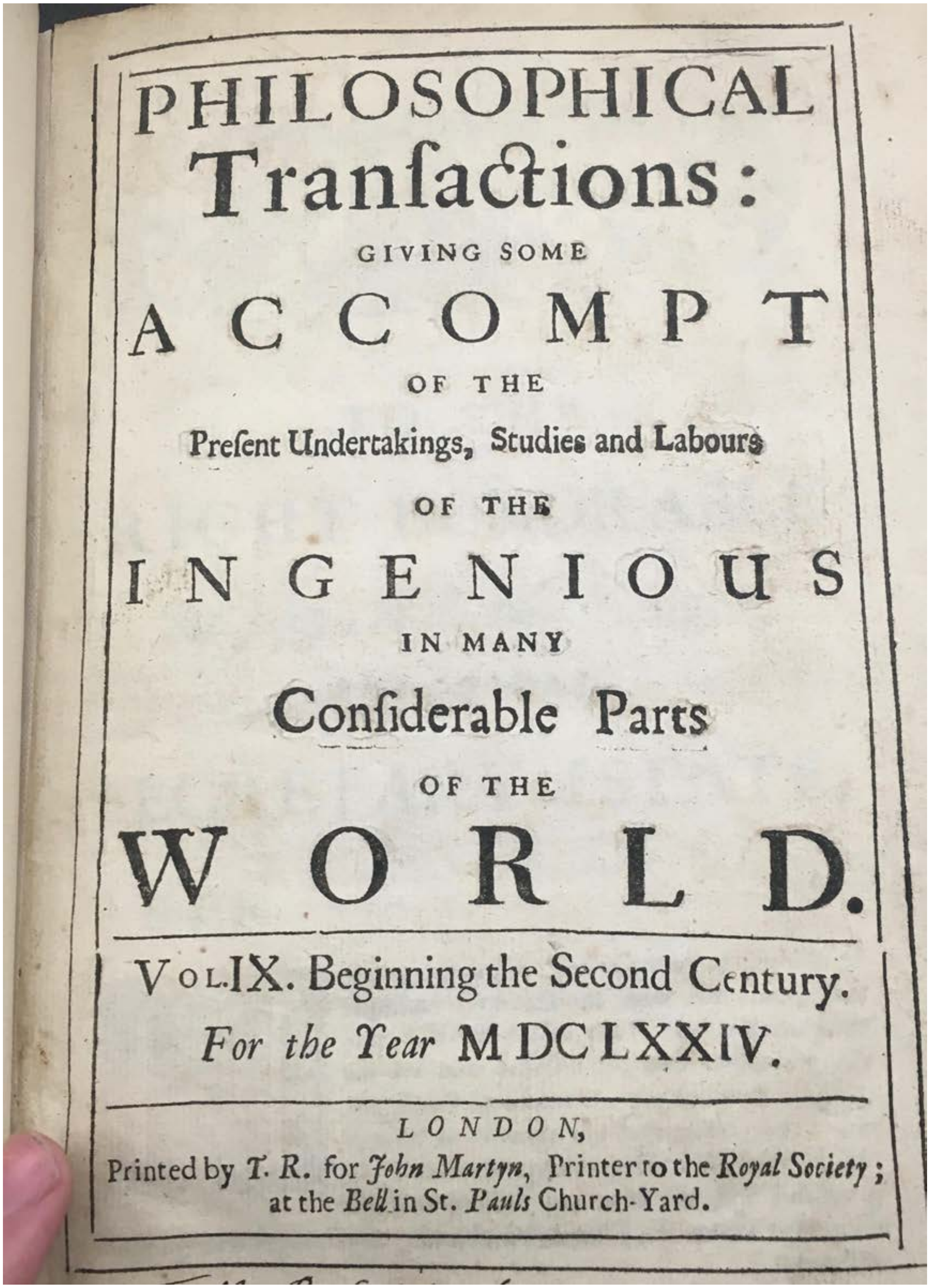
IV. Print and Organization

Coupled with the revolution in science was an organizational revolution that was a reaction against the entrenched curriculum of the medieval university. Learned men such as Robert Boyle, Robert Hooke, Isaac Newton, and Henry Oldenburg began to establish the methodological and organizational basis for a new extra-university scientific society. The instruments of validation theorized by Bacon, Galileo, Descartes, and Boyle remained outside the orbit of the university system, which illustrated just how behind universities were in the rapidly evolving scientific philosophy of the seventeenth century. It was Gresham College, founded in 1598 by private donors that offered the new science its first institutional home of the kind to which Boyle alluded. The college hired professors in astronomy, geometry, and physics, becoming a noteworthy meeting point for men of science. A German gentleman scholar, Theodore Haak, abroad with independent means and excellent family connections, started a correspondence while in England with German-British Polymath Samuel Hartlib. Hartlib introduced Haak to his circle of other notable men including mathematics professor John Wallis and the Bishop of Chester John Wilkins, which allowed Haak to form this knowledge network of written correspondences that he eventually gathered in person.[14] In 1645, Theodore Haak convened his "knowledge network" in professor Samuel Foster's lecture hall at Gresham

[14] Christopher Hill, *Intellectual Origins of the English Revolution* (Clarendon Press Oxford, 1997) Kindle Location 1554 (Kindle Edition).

College, this group came to be known as 'the invisible college.' It was the precursor to the Royal Society of London, which would obtain royal recognition in a charter granted by Charles II in 1662 and 1663. The Royal charter gave the Royal Society of London corporate status, setting it apart from smaller groups. A few years later, a similar royal charter established the Academy of Sciences in France, effectively shifting the balance of scientific power from the small states of Italy and Holland to the larger polities of France and England.[15] What distinguished the Royal Society of London from the Royal Academy in Paris was its good fortune in obtaining the services of polyglot and intellectual Henry Oldenburg, who turned his position as institutional secretary into a formidable platform from which to orchestrate the progress of science via the international scientific correspondence in which he took over from Theodore Haak and filter between quackery and legitimate discoveries by instituting peer review in the late 17th and early 18th century.

[15] James McClellan II, *Science Reorganized* (Columbia University Press, 1985) p. 48



PHILOSOPHICAL
Tranſactions:
GIVING SOME
ACCOMPT
OF THE
Preſent Undertakings, Studies and Labours
OF THE
INGENIOUS
IN MANY
Conſiderable Parts
OF THE
WORLD.

VOL. IX. Beginning the Second Century.
For the Year MDCLXXIV.

LONDON,
Printed by *T. R.* for *John Martyn*, Printer to the *Royal Society*;
at the *Bell* in St. *Pauls* Church-Yard.

Title Page of the Philosophical Transaction Volume IX
Photo: Taken by Ari G. at the Royal Society of London located at 6-9 Carlton House Terrance St. James, London, UK

The purpose of the Royal Society was to keep the community of learned men abreast of new scientific discoveries through meetings and publications. The meetings of fellows of the Royal Society allowed for members to present illustrations of discoveries viewed under the microscope, ideas and theories concerning the natural world, and new scientific technology to other members, but also served as a forum to discuss papers solicited from the Continent.

The Society received a royal charter but did not receive any funding from the crown. In the absence of government support, it could not afford to focus exclusively on the production of a journal, which proved to be unprofitable. It was compelled to enter the commercial book trade as a means of generating income for Society projects. The books that the Society approved and stamped with the coveted royal seal served as literary ambassadors for the enterprise. These works were lavishly produced, containing foldout copperplate, colored engravings that illustrated the experiments and the discoveries that the works discussed, but the publication of such luxurious editions was found to be incredibly expensive. The few impressive books printed and paid for by the Society achieved a modest circulation and now sit in the royal Society Archives on Carlton Place, London, England. The Royal Society stopped funding the publishing of society fellows since it was found to be unprofitable and ultimately threatened the economic viability of the society. Society fellow Isaac Newton's groundbreaking Principia *Mathematica* and fellow Robert Hooke's *Micrographia* did not achieve the same commercial success as a novel by Voltaire or Daniel Defoe, but a few of those who purchased such publications were inspired to enter the discipline as amateurs, the most prominent being Anton Van Leeuwenhoek.

The key to the Society's publishing enterprise was the charter granted to it, which gave it the the ability to license its Royal Seal. It chose to deal exclusively with a single printing house, that of John Martyn and James Allefry, whose names were listed on the title pages of all its publications. Martyn and Allefry gained the privilege to produce all the Society's works, including its periodical publications, in exchange for an oath to uphold Royal Society conventions and maintain the integrity of all its publications. In addition, they were not allowed to print more than the requested number of copies or produce translations of previously published texts, restrictions that were conventional Stationers' practices.[16] Because all of the Society's publications carried the imprint of Martyn and Allefry, it was possible for readers to distinguish the licensed versions from possible pirate editions—an important point at a time of rampant reprinting.

Society Secretary Henry Oldenburg capitalized on the modest sales of the Society's publications and launched a periodical, for which he served as editor. In that capacity, he functioned as a literary ambassador for the Society and its members' discoveries and activities. He titled his periodical *The Philosophical Transactions.* The journal served as a register to in which detailed accounts including the method of derivation of discoveries were published allowing for others to attempt reproducing the result stated in the articles conclusion. The journal featured an article title followed by the scientist/author's name so that the reader could contact the person responsible with any comments or observations on the topic. Each issue of the *Transactions* was assigned a volume number, issue number, and date so a fellow could trace the progression of a discovery by time and contributor. Finally, if a submission was published within the

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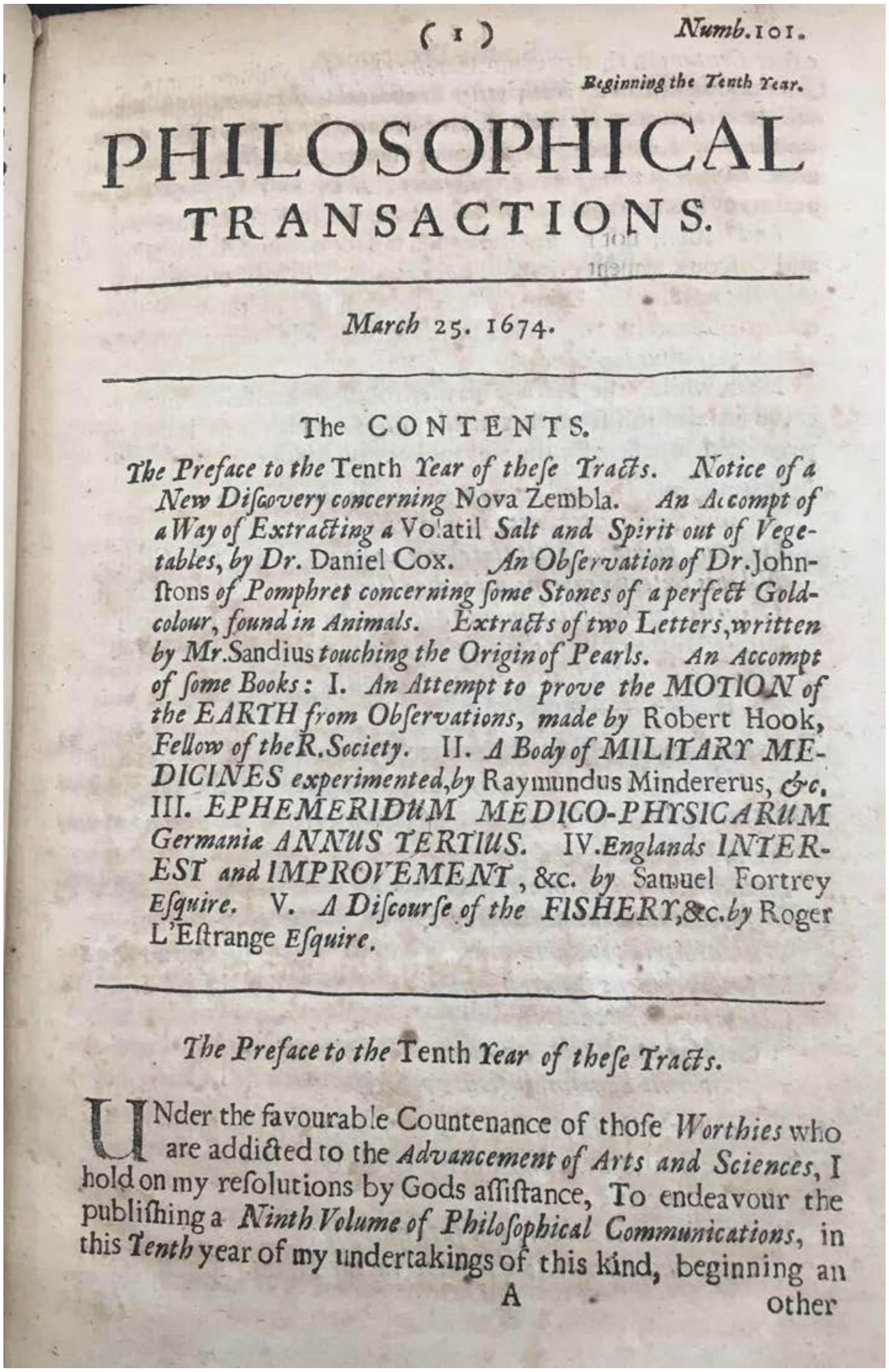
[16] Adrian Johns. "Miscellaneous Methods: Authors, Societies and Journals in Early Modern England" (British Society for the History of Science, Cambridge 2000) p. 166.

periodical than Henry Oldenburg and the esteemed fellows of the Royal Society metaphorically signed off on the submissions validity. Any submission that went unpublished was sent back for refining or ultimately lacked sufficient evidence to meet Oldenburg's standards.

The *Transactional Accounts* were solely Oldenburg's project; he named himself as the editor in the epistle dictum dedicated to King Charles II in the first issue. The expressed goal as written in the introduction was to promote "the improvement of Philosophical Matters, than the communicating to such, as apply their studies and endeavors that way, such things as are discovered or put in practice by others; it is therefore thought fit to employ the press as the most proper way to gratify those, whose engagement in such studies, and delight in the advancement of learning and profitable discoveries"[17] Fellows of the society would debate a proposed discovery and Henry Oldenburg would listen and choose which discoveries he wanted to publish. Occasionally Fellows would intervene prior to publication if they deemed a particular discovery too controversial to be made public. In such cases, Oldenburg, who was the editor and technically had the final word in publication, would acquiesce in the Fellows' decision.

[17] *Philosophical Transaction* (Royal Society of London, 1667) vol. 1.



(1) Numb. 101.

Beginning the Tenth Year.

PHILOSOPHICAL TRANSACTIONS.

March 25. 1674.

The CONTENTS.

The Preface to the Tenth *Year of these Tracts.*

UNder the favourable Countenance of those *Worthies* who are addicted to the *Advancement of Arts and Sciences*, I hold on my resolutions by Gods assistance, To endeavour the publishing a *Ninth Volume of Philosophical Communications*, in this *Tenth* year of my undertakings of this kind, beginning an

A other

Table of Contents and Preface to the Tenth Edition of the Philosophical Transaction.
Photo: Taken by Ari G. at the Royal Society of London located at 6-9 Carlton House Terrance St. James, London, UK

The *Philosophical Transactions* was published as a periodical, a relatively new mode of publication in the history of print.The creation of the scientific periodical was central to the development of modern scientific culture in the 17th century. Gentleman scholars held an ideal that the scientist pursues observation and discovery for the sake of knowledge as an end in itself, not with a view toward publishing discoveries and achieving name recognition, a goal that would have made them seem overly ambitious. For that reason, they were more inclined to circulate their work among a small group of peers in manuscript than to have it printed. There was a risk, however, to this mode of sharing information. Sometimes the manuscript would find its way to an unscrupulous publisher who would illegally publish the discovery and profit from it. Periodicals allowed scholars to make claims to knowledge without appearing unreasonably ambitious.[18] In addition, they allowed individual items of testimony to be published piecemeal rather than all at once.[19] The open-endedness of the periodical reflected the modern scientific ideal: every new discovery was merely provisional, destined to be superseded by another discovery, and so on ad infinitum. The scientist or natural philosopher could publish a discovery in one issue and, if new evidence came to light, amend his report in the next issue. Or another scientist could read of that discovery and publish a challenge to it. In that way, *The Philosophical Transactions* made possible a debate among scholars who might not have been able to communicate with one another in person. Lastly, beside all its other advantages, the periodical cost less than would have been required to print whole books for every new discovery.

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[18] Adrian Johns. 2000. ‘Miscellaneous Methods: Authors, Societies and Journals in Early Modern England’, *The British Journal for the History of Science*, 33.2 pg. 159–86
[19] *Ibid*

Contemporary scholars have yet to attempt a comprehensive study of the circulation of the *Philosophical Transactions*. What we know is that every fellow of the Royal Society of London received a copy. Researchers have therefore been able to reconstruct part of the journal's geographical spread by matching membership with location. Non-members could also subscribe, but the identity and the size of that larger readership have proved elusive. The layout was kept the same for each issue. The title page accompanying every volume stated, "*The Philosophical Transaction:* Giving some Account of the present undertaking, studies, and labors of the ingenious in considerable parts of the world" followed by the volume number, year, city of publication (London) and the names of the royal society printers. The first page of the periodical included, besides the title, the full Gregorian date of publication followed by the contents of the issue stating article titles and occasionally the names of the author if he was a Society member of some note. The first letter of any given article is a large initial capital. In the first issue of the journal, those letters are drawn by hand, but they were printed in all subsequent issues. The copperplate engravings depicting experiments, observations, or the design of a new device take the form of foldouts within the journal. The 17th volume contains a list of errata. Letters from individual readers were sometimes published. The diffusion of the *Philosophical Transactions* extended beyond England to Delft in the Netherlands, where a particular subscriber inspired by Royal Society Fellow Robert Hooke's *Micrographia* and a curiosity for the physical world wrote to Henry Oldenburg with an observation concerning the nature of bees. He told Oldenburg that he wished to share the observation with the Royal Society of London.

V. Anton Van Leeuwenhoek and the Royal Society

In 1699, the Dutch microscopist Anton Van Leeuwenhoek published an account of a revolutionary process for developing and refining glass lenses that allowed him to achieve a sharper image with his microscope than the images observed with the Jannssen microscope. The lenses, which now sit in the University of Utrecht Museum, were remarkably smooth with curved almost aspherical surfaces in which the sharpness of the curvature decreased toward the rim. It was reported that Leeuwenhoek's makeshift laboratory was cluttered with microscopes since he was so skeptical of what he saw under the microscope that he would leave a specimen under the microscope for months untouched and return to it months later from other observations. [20] When he wanted to observe a different specimen, he would build another microscope so that by the end of his life, he had built hundreds of microscopes with his proprietary techniques.[21] Leeuwenhoek never published a set of instructions for how to build his superior microscope lenses. His secrecy in that regard diverged from the common practice among Society fellows—notably, that of Robert Boyle, who famously published detailed instructions for how to construct the pneumatic air machine. Instead, Leeuwenhoek merely bequeathed a few of his inventions to the Royal Society upon his death.

The first mention of a M. Leeuwenhoek to be printed in the *Philosophical Transactions* was in the 8th volume, dated 1 January 1673. Oldenburg entitled the article, "A specimen of some observations made by a microscope, contrived by M. Leewenhoeck in Holland, lately communicated by Dr. Regnerus de Graaf." The title of an article usually denotes the nature of the article or reported observations, but this did neither.

[20] Paul De Kruif, *Microbe Hunters* (Harcourt Inc. Publishing, 1996) Ch. 1. Pg. 5
[21] *Ibid Pg. 5*

Instead, it prominently featured the name of Dr. De Graaf. Though not a fellow of the Royal Society, De Graaf was an established Dutch physician and anatomist; he had corresponded with Henry Oldenburg and was known for his contributions towards the science of reproductive behavior and anatomy. Under the title appears a paragraph from a letter by Dr. De Graaf, which refers to "M. Leuwenhoek excellency in Microscopic observation."[22] The endorsement by De Graf, a learned and established man of science, served as a testament to the character of the relatively unknown Leeuwenhoek.

Such an endorsement, however, was not enough in itself to validate Leeuwenhoek's observations. These are numbered from 1 to 5 with the first observation concerning the stalk or skin of a vegetable and the four remaining ones concerning the sting of a bee. Leeuwenhoek explains that his observations regarding the sting of a bee differ from previous observations made by *Hooke*: "I find [it] to be of another make than it * hath been described by others."[23] While he had set out to corroborate the accounts of others, his observations carried him in a different direction. He proceeds to describe what the microscope had revealed to him: the sting of the bee, the eye of the bee, and other components of the bee's anatomy, including its teeth-like bristles on the limbs, which he names scrappers. The article concludes with some remarks by editor Oldenburg: "So far this Obsirver (sic); who doubtless will proceed in making and imparting more Observation."[24]

The next article by Leeuwenhoek, published in the subsequent volume of the *Philosophical Transactions*, bears only his surname and dispenses with both a

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[22] *Phil. Trans.*,(Royal Society of London, 1673) vol. 8.
[23] *Ibid*
[24] *ibid*

preliminary letter of endorsement and a concluding remark by the editor. Leeuwenhoek begins with an expression of gratitude to the *Transactions'* editor, thanking the Society for encouraging his observational curiosity by its acknowledgment of his discoveries. Such an expression of gratitude reflected the author's status as a correspondent of the Society. It would have been unnecessary for the Society's established fellows to include such a statement in their articles for *The Transactions*.

Leeuwenhoek's second article details an observation on the nature of small red globules in the blood. Physician and fellow of the Royal Society William Harvey had published his treatise *De Motu Cordis* forty-six years earlier, a work in which he had described the circulation of the blood but not what we would today call the "red blood cell." For his experiment, Leeuwenhoek drew blood from his vein and examined it under the microscope. He was able to detect what he calls "red globules," which are heavier than the "crystalline liquid" of his blood.

Before describing these observations, he sets forth the method by which he obtained the blood for observation. Figures on the following page depict the glass pipette that he used to draw the blood from what he stated was the first joint of his thumb. He states that along with his letter he included, "some of the said hollow pipette, by the means of which I hope my above- mentioned speculations will be verified."[25]

In the same article, Leuwenhoek also discusses his observations pertaining to the brains of a cow, describing the white and grey substance (today termed white and grey matter) of the brain. He utilizes the same glass pipette in his procedure. He describes a procedure by which he thrust the pipette into the white of the brain, using his mouth as

[25] *Phil. Trans.,* (Royal Society of London, 1673) vol. 9.

suction to draw out a little part of the brain, which he viewed in the same manner as he described in his account of the blood. An asterisk directs the reader to a marginal note in which he acknowledges a possible imperfection in his method. The problem, the note states, is that the tube used to extract the brain was narrow. In passing through the tube, the brain was compressed, and the fine globules of white matter may have been altered. Such marginal notes were unusual in the *Transactional Accounts*. Leeuwenhoek strove for perfection and his acknowledgment of the imperfection with regards to his technique could be considered an element of fallibility as to his account of the observation. Leeuwenhoek acknowledges that later observers of the brain's white matter might see details unnoted by Leeuwenhoek simply because they didn't use a glass tube to obtain the specimen. Part of his genius is that he was acutely aware that his observations were to further along scientific understanding and not definitive principles which were attempted by Royal Society Fellow's like Robert Boyle and Sir Isaac Newton. Definitive observations would have stifled curiosity surrounding microscope matter. If the wing of a bee that lacked bristles was viewed and it was proclaimed that bee's wings never bristles then another observer might decide to turn his microscope to another specimen and leave bee's wings alone. Leeuwenhoek never proclaimed that his observation was definitive, though he was unaware of the concept of phenotype mutations he was aware that though the five bee's wings he viewed lacked bristles it does not rule out that he might come across a bristled wing. He ends his observation on the white matter of the brain by saying that he will return to an examination of the brain at his earliest convenience. While some other accounts published in *The Philosophical Transaction* had definitive conclusions, Leeuwenhoek's are provisional. He is committed to scientific inquiry as an open-ended process. .

Leeuwenhoek makes several more observations on other specimens within this specific account presented in volume nine of *The Philosophical Transactions*. In his single note to the Oldenburg which was subsequently published he claims to have observed "small red globules in the blood, parts of a bone, the liver of a sheep, brains of a cow, the marrow of the back bone, the flesh of a cow, and human spittle."[26] Having observed red globules in which he described in all of these forms of organic matter from once living specimens, he finally concludes within this entry as to the nature of these globules:

> All bodies made out of fluid matter do consist of globules and am therefore of opinion that if a drop of water could be placed in the free air, it would be a perfectly round body and consequently when out of any fluid matter in our body there are made consistent particles that they also must be preferred together on all side.[27]

Leeuwenhoek returns to the red globules in his account of 14 April 14 1684, a report on the nature of the crystalline liquid of the eye. In this article, he attempts to deduce the purpose of these free-floating globules. Since his first published observation in 1673, he had been interested in the matter causing the redness of blood and deduced it to be globules. To confirm that hypothesis, he had examined the blood of oxen, sheep, and rabbits as well as humans and saw no difference in magnitude, shape and size, between the animal and human globules. On that basis, he had concluded that the matter

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[26] *Phil. Trans,* (Royal Society of London, 1673) vol. 9.
[27] *Ibid*

responsible for making all blood red was these globules.[Previously, the globules were a natural phenomenon that occurred in all liquid but upon examine the globules in the blood of different organisms he deduces that maybe these red circular globules are unique to and uniform among all living creatures. Leeuwenhoek refrains from proclaiming that red globules are found in all living organisms in a circular like shape. Instead he attempts to search for more evidence of his hypothesis and sought out more organisms' blood for observation to be described in future letters to the Royal Society.]

In a letter of 14 April 1684, Leeuwenhoek reports on observations that he had made of the blood of a salmon, a cod, and frogs. On the strength of those observations detailed in his letter, he concludes that that the matter responsible for making the blood red is oval shaped and flattish. Likewise, when examining the blood of several birds, he finds the red globule matter to be similar to that in the fish blood . The new evidence leads him to the conclusion that all animals, whether birds or fish, have globules shaped differently from those of man, but he does not assert that his conclusion is irrefutable. The final sentence of the article registers his attitude of hesitation: "and if hereafter I chance to find the contrary, I will advise you thereof."[28]

True to his word, Leeuwenhoek published an entry in *The Transactions* three years later announcing findings at variance with his original observations of blood globules. The globules he had observed from a sample drawn from his thumb had originally appeared to him as firm and hard; those from the new samples, by contrast, appeared to be soft. He attributes the change to a change in his health. He writes that he had been in poor health when conducting the first observation three years earlier. On that basis, he speculates that perhaps the globules in the blood change in size, appearance, and

[28] *Phil. Trans*. 1684 14, 780-789, published 20 January 1684

thickness in response to illness in living organisms. He appeals to the verdict of other fellows in evaluating his hypothesis: “Meantime I shall be glad to hear how my observations are received, and what objection are made against them, remaining.” Leeuwenhoek was able to discern minute differences between globule appearances when taken from fish, birds, and humans. Yet, knowing that few others had observed globules, he defers to the judgment of the Fellows of the Royal Society. He forgoes a definitive conclusion because he realizes that his observations are easily reproducible and others might observe something different. It was uncharacteristic of this credible scientist to proclaim something outside the realm of belief like creatures living and moving in pond water. Perhaps it was the credibility that he amassed with his previous observations on the reporting of red globules that led to this new observation to be met with skepticism instead of outright dismissal considering the absurdity of the idea.

Oldenburg, who had always published Leeuwenhoek’s letters without delay, received a letter from the ‘Man of Delft’ in October 1676 that gave him pause. It was Leeuwenhoek’s famous ‘letter on protozoa.’ Oldenburg subsequently translated it from Low Dutch to English so that it could be presented at the next Royal Society meeting. The letter opens with the announcement of a revolutionary discovery:

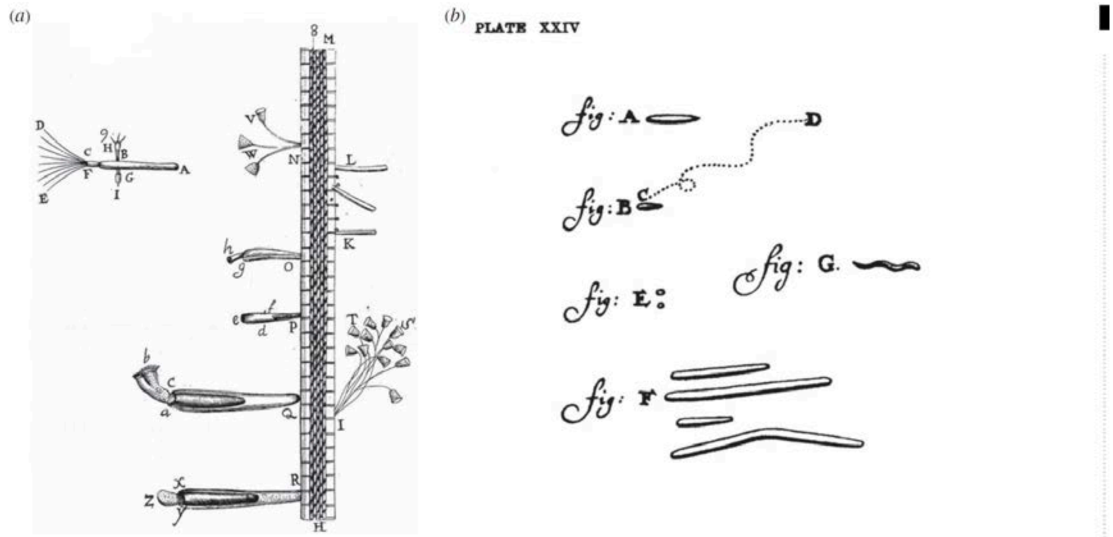
> In 1675 I discovered living creatures in Rainwater, which had stood, but few days in a new earthen pot, glased blew [i.e. painted blue] within. This invited me to view this water with great attention, especially those little animals appearing to me ten thousand times less than those represented by Mons Swammerdam and

> called by him Water fleas or Water-lice, which may be perceived in the water with the naked eye.[29]

Following their discussions, the fellows instructed Oldenburg to inquire into Leeuwenhoek's method of observing and request drawings.[30] They wanted to understand the technique by which he had managed to see something so extraordinary and unknown before they endorsed the discovery by publishing an account of it. Leeuwenhoek replied in a March letter, "that he drew a small amount of the water to be observed into a capillary tube to set before his microscope."[31] But this short account was not enough to allay the skepticism of the Royal Society's members and persuade them to publish his account. Leuwenhoek employed the service of a draftsman, "whose regular gasps of astonishment when shown various little animals punctuate Leuwenhoek later letters."[32]. In October, Leeuwenhoek followed his draftsman's drawings with a signed testimonial of eight respectable visitors to satisfy the gentleman of the Royal Society of London. The forwarded letter stated that these other eight individuals also saw "the existence of thousands of animalcules in a sample of water the size of a millet grain."[33] During this interim period, the established observational giant Robert Hooke attempted to reproduce Leeuwenhoek's results. Hooke writes that, "it seems very wonderful that there should be an infinite number of animalls in soe imperceptible quantity of matter…to find that these were gygantick [gigantic] monsters [protozoa] in comparison of a lesser sort which almost filled the water [bacteria]."[34] After a month of peering at water droplets, Hooke

[29] *Phil. Trans*. 1677 12, 780-789, published 20 January 1677
[30] Ruestow, p. 154
[31] *Ibid*.
[32] Nick Lane "The unseen world: reflections on Leeuwenhoek (1677) Concerning little animals" *Philosophical Transactions* (The Royal Society Publishing, 2015) pg. 4
[33] *Ibid*.
[34] Clifford Dobell. *Anton Van Leeuwenhoek and his Little Animals* (Russell and Russell Press, 1958) p. 183

was finally able to confirm the presence of animalcules, thus persuading the Society to proceed with the publication of Leeuwenhoek's account. The letter "concerning little animals by him observed in rain-well-sea- and snow water; as also in water wherein pepper had lain infused" was published in volume 12 of the *Philosophical Transactions* in 1677. Leeuwenhoek depicts these animals as having little horns that they use for movement and describes the patterns of their movement. The letter contains multiple dated observations of the rainwater. This repetition of the experiment in order to confirm initial observations calls to mind the method that Leeuwenhoek had employed in his observations of blood globules, but, in this case, all the experiments are reported in a single letter. Perhaps Leeuwenhoek realized the gravity of his claim and employed the rhetorical techniques conceived earlier by Robert Boyle to convince the fellows and publish his claim to the learned community. Leuwenhoek sought out the testimony of other learned men to confirm his results, employed a draftsman to illustrate his findings, and included just enough information on the method of obtaining pond water to allow others to reproduce his experiment. The presentation of scientific findings followed by testimony and reproducibility was the earliest version of the scientific peer review process that modern scientific publications utilize today. The discovery of microorganisms has led the modern scientist to term Anton Van Leeuwenhoek as the founder of the field of microbiology, but it was his exhilaration in discovery, coupled with fearlessness and confidence in his ability to interpret and present never-before-seen observations to the more learned scientific world, that might be considered his greatest contribution.



a) Rotifers, hydra and vorticellids associated with a duckweed root, from a Delft canal. Image from Leeuwenhoek letter, 1702..
(b) Bacteria from Leeuwenhoek’s mouth; the dotted line portrays movement. Image From Leeuwenhoek letter, 1683.

VI. Conclusion

It has been argued that the scientific revolution was not a revolution in ideas so much as a revolution in the method of discovery and presentation of ideas. In order to win assent, a new discovery had to rest on fact, observation, and calculations. But how was one to evaluate the credibility of claims to knowledge? Robert Boyle confronted that challenge when he presented the technology of the pneumatic air machine and the discoveries that the technology had allowed him to make. The Royal Society relied on the power of the inductive approach to evaluate claims to knowledge. When presented with the new and unheard-of observation that within a few drops of rainwater lived thousands of moving animals, the fellows were understandably skeptical. The reputation that Leeuwenhoek had established for his work on the red globules of blood and vitreous humor of the eye enhanced the credibility of his claims about animalcules. But what ultimately tipped the balance in his favor was his method of observation: his repetition of experiments and his willingness to revise conclusions in the light of fresh evidence. Persuaded by his method, the Society's members agreed to investigate Leeuwenhoek's claims rather than dismiss them out of hand. It was only after a number of other scholars had succeeded in reproducing Leeuwenhoek's observations that his article on the animalcules in water was finally published in the *Philosophical Transactions*.

The case of Leeuwenhoek illustrates the crucial role of the scientific periodical in establishing the credibility of a scientific discovery. It is a lesson we would do well to ponder today in the current realm of academic science, the credibility of certain journals and organizations is debatable, as science has become more profit driven and less exploratory. Journals are under increasing economic pressure to scale back the vetting process and more and more scholars are tempted by the ease and speed of on-line publishing. Yet there are a number of legitimate scientific journals in the twenty first century that present the latest advancements in medical treatment or findings in biology. Those journals continue to honor a peer review process of which the origins can be traced back to the editor of the *Philosophical Transactions*, Henry Oldenburg. In the seventeenth century, such a process allowed Leeuwenhoek's observations on animalcules to achieve validation in the eyes of the scientific community. It remains an important touchstone of the commitment to scientific method today.

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