The Discovery of Microorganisms Revisited

A close reading of 17th-century documents shows that Hooke, rather than Leeuwenhoek, was the first to observe a microorganism

Howard Gest

Two remarkable geniuses, Robert Hooke and Antonie van Leeuwenhoek, deserve the credit for discovering microorganisms in the 17th century. A complex series of events and a common interest in microscopes were instrumental in leading these two men from very different backgrounds to codiscover the microbial universe. Their separate journeys into that realm were recorded between 1665 and 1678 in publications of the Royal Society of London.

Among Hooke's outstanding achievements is the first published description of a microorganism. From Hooke's excellent drawing in *Micrographia* (1665), mycologists identify Hooke's specimen as the microfungus *Mucor*, the common bread mold (Fig. 1). In *Micrographia,* Hooke illustrated microscopic views of diverse biological objects, including sponges, wood, seaweed, leaf surfaces, hair, peacock feathers, fly wings, eggs of silkworms, mites, a flea, and a louse—as well as that of a mold. Hooke obtained the microfungus specimen from a "small white spot of a hairy mould," many of which he observed on the red sheepskin covers of a small book. He called the organism a "microscopical mushroom." Although he attempted to observe the "seed" (now called sporangiospores) from which it develops, the relatively low magnifying power of his microscope made that effort impossible.

Robert Hooke as well as Antonie van Leeuwenhoek should be considered responsible for "fathering" modern microbiology

Hooke advanced the techniques of microscopy in many ways that are detailed in the Preface of *Micrographia* and in a 1678 treatise, *Lectures and Collections; Microscopium*. Hooke's Preface to *Micrographia* also describes how to make a single-lens microscope of the same kind that Leeuwenhoek used in studies that began almost a decade later.

According to my analysis along with the important studies of microscopist Brian Ford, Hooke rather than Leeuwenhoek was the first to observe and document the existence of a microorganism. Moreover, his *Micrographia* provided the basic model and "trigger" for Leeuwenhoek's subsequent discoveries of other microbes during the the 17th century. Thus, Robert Hooke as well as Antonie van Leeuwenhoek should be considered responsible for "fathering" modern microbiology.

A Glimpse of Robert Hooke's Illustrious Career

Robert Hooke (1635–1703) was enrolled as an undergraduate at Christ Church College at the University of Oxford but apparently never obtained a degree. Nonetheless, he became associated with a brilliant group of scholars, including Christopher Wren and Robert Boyle, who met regularly to discuss a broad range of scientific problems.

In due course, this group became the nucleus of the Royal Society. Hooke, a founding member of the Society, served as "Curator of Experiments" from 1662–1677. His duties included

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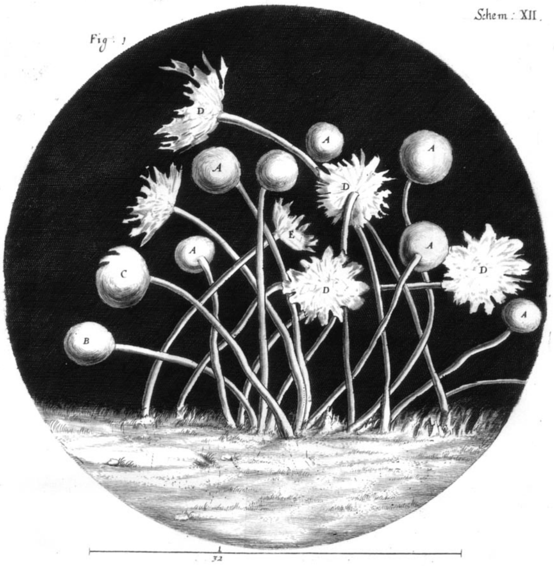
FIGURE 1



Microscopic view of a "hairy mould" colony described by Robert Hooke in 1665 (in *Micrographia*). This image was the first published depiction of a microorganism. The reproductive structures (sporangia) are characteristic of the microfungus *Mucor*. Sporangia in different stages are identified by the letters A, B, C, and D. Hooke included a scale reference; the length of the bar under the diagram represents 1/32 of an inch. Image courtesy of The Lilly Library, Indiana University, Bloomington.

conducting "considerable experiments" and doing other research projects officially recommended to him. Hooke soon became a commanding intellectual force in the Society and, as Curator, provided the main substance of many meetings. During April 1663, Hooke lectured on the structure of plant tissues, such as cork and moss, and coined the term "cell." In *Micrographia*, the structure of cork is detailed in Obs. XVIII: "Texture of cork, and of the cells and pores of some other such frothy bodies."

Hooke's scientific interests were broad, and his genius many sided. Physicist J. D. Bernal wrote of Hooke in 1965 that his "interests ranged over the whole of mechanics, physics, chemistry, and biology. He studied elasticity and discovered what is known as Hooke's Law. . . .he invented the balance wheel, the use of which made possible accurate watches and chronometers; he wrote *Micrographia*, the first systematic account of the microscopic world, including the discovery of cells; he introduced the telescope into astronomic measurement and invented the micrometer." In 2003, the tercentenary of Hooke's death, several new biographies were published, describing his life and scientific achievements as well as his important architectural contributions while London was reconstructed following the Great Fire of 1666.

Antonie van Leeuwenhoek's Unusual Career

Leeuwenhoek (1632–1723), who had little formal schooling, opened a shop at age 22 as a draper in Delft, Holland. Indeed, his scientific career likely traces to his use of low-power magnifying glasses to inspect cloth.

Leeuwenhoek developed the ability to make superb microscopes containing single lenses that were about 1 mm in diameter. Leeuwenhoek was a keen observer and had extraordinary curiosity, which he soon focused on the natural world. For instance, he was the first to observe and describe sperm cells of animals, red blood cells, protozoa, and yeast cells. Although it was then thought that maggots, fleas, and the like formed through "spontaneous generation," he showed that such creatures hatch from eggs.

Leeuwenhoek communicated his observations to the scientific world in an unorthodox way. Dutch acquaintances, who were corresponding members of the Royal Society, suggested that he describe his findings in letters addressed to the Society. During the rest of his life, Leeuwenhoek communicated some 200 letters in Dutch, many of great length. Between 1939 and 1983 the "Leeuwenhoek Letters" were translated into English by large committees of Dutch scientists, yielding 11 volumes with English and Dutch texts on opposing pages. These volumes include extensive annotation. Several footnotes show that Leeuwenhoek was familiar with *Micrographia* even before he began sending letters to the Royal Society.

One of Leeuwenhoek's greatest contributions to biology was the discovery of bacteria in 1676. As might be expected, his observations and de-

Valuing Impact of History on Science, Witnessing Science's Impact on History

Howard Gest feels very strongly about the impact of history on science. "I believe that many young scientists know little about the early history of their own research areas, and I think this limits their understanding of how major discoveries are made," he says, adding that too often they assume that contemporary biological knowledge is nearly complete. "History clearly shows that biology is far more complicated than each generation thinks it is."

Gest came to this realization years ago, influenced by the late J. H. "Jack" Hexter, a noted historian and professor of history at Washington University, St. Louis, Mo., where Gest knew him, and Yale University, New Haven, Conn. "Hexter once said: 'History with a capital H deals with major trends, large movements, deep running tides, portentous rumbles. When a "small h" historian fixes his attention on a fragment of the past washed up on the littered beach of the present, he is likely to ask simple questions about it: How did it get there? What the devil is it? What was it for? Where is it from? What happened to it?'," Gest says. "Hexter's remarks made me realize that I had become a 'small h' historian of microbiology and biochemistry."

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Gest was born in London, and emigrated in infancy with his family to America. He received a B.A. in bacteriology from the University of California, Los Angeles (UCLA) in 1942, and his Ph.D. from Washington University in 1949. While attending UCLA, he spent the summers of 1941 and 1942 assisting Max Delbrück and Salvador Luria, who were studying bacterial viruses. Although Gest began graduate work with Delbrück at Vanderbilt University, World War II intervened. Later in St. Louis, he did research with Alfred Hershey, using the radioactive isotope P_{32} to examine what happens to phosphorus-containing cell components when bacterial viruses replicate. These studies culminated with their discovery of P_{32} "suicide" of bacteriophage.

During World War II, Gest was involved in the Manhattan Project with physical chemist Charles Coryell—one of Gest's teachers at UCLA—first at the University of Chicago, and later at Oak Ridge, Tenn. His role was to conduct basic research on the radioactive elements formed in uranium fission. He looks back at that period with conflicted emotions. While proud of his contribution toward developing the atomic bomb, he was troubled by the real possibility that its use would result in the needless loss of life—a fear that ultimately became a reality. Gest was among those scientists who signed a petition that urged President Truman to consider the moral implications of dropping the bomb, and asked that the Japanese first be offered an opportunity to surrender. Truman apparently never saw the document (see http://www.bio.Indiana.edu/Gest/).

"When this huge project was successful, we felt great pride in our work; we felt it was very important for the security of the United States," Gest says, recalling the Manhattan Project. "But we were very disappointed in how the bombs were used. We'd hoped they would be used in such a way that would not lead to the death of many innocent civilians. And we were very perturbed that the petition never reached President Truman."

Howard Gest

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Gest no longer engages in experimental research. Instead he spends much of his time writing about the history of microbiology and biochemistry. He also is a continuing and familiar presence among graduate students and postdoctoral fellows, with whom he continues to work. "I go to the university every single day," he says.

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scriptions of these very minute organisms were at first considered dubious. Unknown to Leeuwenhoek, Hooke was appointed Secretary of the Royal Society in 1677 and in this capacity he received a letter from Leeuwenhoek, dated 5 October 1677, which described bacteria in a pepper-water infusion. The large number of bacteria in one drop astonished Leeuwenhoek, who wrote, "This exceeds belief." Accordingly, he included testimonials of "eight credible persons" who affirmed his observations.

In *Microscopium* (1678), Hooke confirmed Leeuwenhoek's observations of bacteria, writing "much to wonder I discovered vast multitudes of these exceeding small creatures which Mr. Leeuwenhoeck had described. . .and some of these so exceeding small that millions of millions might be contained in one drop of water." Hooke's confirmation and the authority of the Royal Society proved momentous for Leeuwenhoek and his reputation. In 1680, he was elected to the Royal Society and later became a celebrity, visited in Delft by notables, including Tsar Peter the Great.

Intertwined Beginnings of Microscopy and Microbiology

There is no doubt that Hooke was the first to describe and depict a microorganism in the scientific literature, and his published descriptions of microscopic techniques paved the way for improvements. In contrast, Leeuwenhoek was notoriously secretive about his lenses and his techniques. In 1685, 20 years after Hooke published *Micrographia,* the Royal Society sent Thomas Molyneux to visit Leeuwenhoek and obtain information about his methods. Molyneux's report describes several of Leeuwenhoek's low-power microscopes but also comments:

> "Such were the microscopes, which I saw, and these are they that he shews to the curious that come and visit him: but besides these, he told me that he had another sort, which no man living had looked through setting aside himself; these he reserves for his own private observations wholly, and he assured me they performed far beyond any that he had shewed me yet, but would not allow me a sight of them. . .. as for the microscopes I looked through, they do not magnify much, if any thing, more than several glasses I have seen, both in England and Ireland: but in one particular, I must needs say, they far surpass them all, that is in their extreme clearness, and their representing all objects so extraordinary distinctly."

This and other contemporary comments leave little doubt about Leeuwenhoek'secretive character. Other parts of the historical record show that he sometimes could also be obscure if not outright misleading.

Leeuwenhoek Surely Was Aware of Hooke's *Micrographia*

More than a decade ago, microscopist Brian Ford, a Fellow of Cardiff University, Cardiff, Wales, United Kingdom, drew attention to a passage in the Preface to *Micrographia* where Hooke writes an exact "prescription" for making what later was called a "Leeuwenhoek microscope." According to Hooke:

> "If you take a very clear piece of *Venice* Glass, and in a Lamp draw it out into very small hairs or threads, then holding the ends of these threads in the flame, till they melt and run into a small round Globul, or drop, which will hang at the end of the thread; and if further you stick several of these upon the end of a stick with a little sealing Wax, so as that the threads stand upwards, and then on a Whetstone first grind off a good part of them, and afterward on a smooth Metal plate, with a little Tripoly, rub them till they come to be very smooth; if one of these be fixt with a little soft Wax against a small needle hole, prick'd through a thin Plate of Brass, Lead, Pewter, or any other Metal, and an Object, plac'd very near, be looked at through it, it will both magnifie and make some Objects more distinct than any of the great *Microscopes*."

This paragraph aptly describes how to build a single-lens microscope identical to what Leeuwenhoek later perfected. "The design of the hand-held microscope that Leeuwenhoek used throughout his researches was derived from Hooke's published account," Ford concludes. Hooke noted in several publications that using this kind of microscope strained his eyes, explaining why he preferred larger microscopes with two lenses.

In his 28 April 1673 letter to the Royal Society, Leeuwenhoek briefly describes a "mould" and a "lowse"—closely matching Hooke's lengthier descriptions of similar objects in *Micrographia* that were published eight years earlier. In that letter, Leeuwenhoek barely alludes to similar observations by "others." That word "in all probability is a reference to Hooke's *Micrographia,*" according to a footnote by Dutch scientists in the edited *Leeuwenhoek Letters*.

A close comparison leaves no doubt. Indeed, additional examples indicate that Leeuwenhoek studied illustrations in *Micrographia* and had some of Hooke's descriptions translated. In a 1676 letter to Henry Oldenburg, who preceded Hooke as Secretary of the Royal Society, Leeuwenhoek wrote that he had friends who would translate French or Latin, adding "I cannot help myself with the English language since the death of a certain gentleman who was proficient in this language." However, the Dutch editors of Leeuwenhoek's letters note that, throughout Leeuwenhoek's lifetime, English-speaking communities thrived in Delft and many of their members were competent in Dutch. Ford also documents Leeuwenhoek's access to English-Dutch translators.

Why Have Hooke's Findings, Establishing His Priority, Been Largely Ignored?

With this background, one may well ask why Hooke's primary role in discovering microbial life is barely mentioned in standard accounts. Milton Wainwright of Cardiff University points out that accounts of the early history of microbiology typically begin with the "first sighting" of microorganisms by Leeuwenhoek. For example, the *Autobiography of Science* refers to Leeuwenhoek as "first of the microbe hunters."

"Unfortunately, much of what is taught about the history of microbiology has been oversimplified to the point where plain untruths are being told; at best a fascinating and convoluted story has been reduced to the minimum for easy, uncritical consumption," Wainwright comments.

I believe that Hooke's major contributions have been minimized or ignored because of the slanted perspectives fostered by two widely read books. The more influential is the scholarly 1932 book by protozoologist Clifford Dobell, *Antony van Leeuwenhoek and his "Little Animals."* Dobell took a limited view of the scope of microbial life, stressing Leeuwenhoek's observations of protozoa and bacteria. Ford describes Dobell's biography as "a monumental, if partisan, study." Dobell's book, which omits any mention of Hooke's discovery of microfungi and his contributions to microscopy, inexplicably dismisses Hooke in a footnote:

> "Dr Robert Hooke, an original Fellow of the Royal Society, was also an original and eccentric genius and inventor. His contributions to science are too well-known and numerous to mention; though his influence on his contemporaries, and the part he played in the early days of the Society, are only just beginning to receive their due recognition. . . .*It is impossible and unnecessary to discuss this remarkable man and his work here"* [italics added].

Although Dobell's book contains 34 citations to Hooke in its extensive index, they are trivial, mainly noting the dates of various letters. The index does not cite *Micrographia*, which is simply listed among "other References and Sources."

Dobell's biography was widely read by generations of microbiologists, many of whom were also exposed to Paul de Kruif's popular 1926 book *Microbe Hunters* and read its first chapter, "Leeuwenhoek, first of the microbe hunters." The first paperback edition appeared in 1940 and by 1963 there was a 28th printing! This account mentions Hooke only once, simply as a person who confirmed Leeuwenhoek's discovery of bacteria. It is no wonder that over the past 70 years, microbiologists and the general public heard little or nothing about Hooke's seminal contributions to microbiology.

Leeuwenhoek's career was obviously very unusual and, as such, had a strong element of drama. He was generally seen as a person of genius who made great discoveries while isolated from others pursuing the natural sciences during the 17th century. This personal scenario seems tailor-made for de Kruif's style, which popularized historical events replete with imagined dialogues. Notwithstanding those vividly portrayed accounts, Hooke rather than Leeuwenhoek was the first to observe and document the existence of a microorganism.

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