The Scanning Microscope and Leeuwenhoek's Legacy

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After some 350 years, newly discovered Leeuwenhoek microscopes are emerging. Two have now been subject to examination with the scanning electron microscope (SEM). Their maker, Antony van Leeuwenhoek, was the first microbiologist in history. He died 300 years ago, having shown us protozoa, bacteria, and spermatozoa for the first time. His work on plant anatomy was remarkably accurate, and he did much to dispel the dogma of spontaneous generation. I found his source of inspiration in Robert Hooke's great work *Micrographia*, which was published in 1665 and was the talking point of London society when Leeuwenhoek made a visit to England the following year[1].

Hidden in the unnumbered pages of the preface to *Micrographia*, and never cited by other scholars, I found that Hooke had described in detail how to make what we now call a Leeuwenhoek microscope[2]. Not only that, but the first specimens Leeuwenhoek sent to the Royal Society (the publishers of *Micrographia*) had been described by Hooke, and in the same order[3]. After my discovery of Leeuwenhoek's original specimens, the Royal Society allowed me to take small portions of each one to Cardiff University, where I am a Fellow, so I could use the Cambridge Stereoscan scanning electron microscope (SEM) to examine them in detail[4]. The bulk was left untouched, so that future analysts could return to them for future study, uncontaminated by the modern world.

There was a surge of public interest following the international publicity given to my discoveries, and an unknown Leeuwenhoek microscope was taken to the Boerhaave Museum in Holland. Someone had realised what it might be. This was not just a fluke, for the interest continues – and others are still coming to light to this day[5]. In December 2023 yet another came to light. It was found during a house clearance in East Anglia and was submitted to Christie's auction house in London, who had sold one of the known Leeuwenhoek Microscopes in 2009 for close to half a million dollars[6]. This one didn't make the mark; it cost the unknown Californian purchaser a mere £175,000.

A house clearance in East Anglia in December 2023 revealed this little microscope which proved to be hand-made by the Dutch pioneer Leeuwenhoek some 350 years ago. The main screw was used to set the specimen at the desired height; a silver pin held it close to the single lens.

Mr James Hyslop, head of science and natural history at Christie's, spent many years at the Whipple Museum for the History of Science in Cambridge, and fully supported my proposal for scientific investigation, by examining the microscope in detail. He kindly agreed to bring it to the Cavendish Laboratory at Cambridge University for the day, so that I could scrutinise it under the SEM[7].

The Quest for Authenticity

This was the second Leeuwenhoek microscope I had analysed in this way. The first was a brass instrument found in the Netherlands in landfill mud dredged from a canal in Delft, Leeuwenhoek's home town. The reaction of the Boerhaave Museum (who have several Leeuwenhoek microscopes in their collections) was that this newly discovered brass microscope was one of their replicas that had been carelessly discarded. Placed side-by-side with a known copy, they clearly have much in common[8].

There was less doubt expressed over the silver instrument; nobody ever created replicas of Leeuwenhoek's silver microscopes, due to the value of the materials. The way authenticity has always been established is based on provenance or personal judgement. For most of the surviving Leeuwenhoek microscopes there is limited documentation, and most lack a link back to Leeuwenhoek's time. I set out to establish a protocol that would allow for objective authentication. The SEM allows us to discern how these little instruments were made, and that provides the evidence we need.

Low-power SEM is an unusual technique to apply to antique instrumentation. It combines images that have the astonishingly high resolution we expect

This brass microscope was found during 2015 in mud from a canal in Delft, where Leeuwenhoek lived and worked. It was sold by a collector, along with a few coins from the Dutch East India Company, describing it as a 'weird kind of drawing instrument'.

from electron microscopy, with the clarity we find when secondary electrons from a rasterised scan are correlated to generate an image. The reductionist aim with electron microscopy has long been to obtain images of greater magnification and higher resolution, though I have shown that sub-micron resolution in combination with low power magnification confers unforeseen benefits[9].

Harnessing the SEM

Although large-chamber SEMs are available for industrial applications, the specimen chamber of a conventional scanning electron microscope imposes restrictions on the area that can be scanned. Images captured in this case, using the Hitachi S-3400N SEM at the Cavendish Laboratory, University of Cambridge, measured ~1-2 mm so imaging a Leeuwenhoek instrument can involve the capture of ~100 separate files. Changes in focus or positioning can lead to minor perturbations in contrast, brightness, proportion or dimensionality, so assembling an image can require much manual adjustment from frame to frame. Once completed, the appearance of these diminutive instruments is gratifyingly detailed and allows us to ascertain methods of manufacture and assembly. The greatly increased resolution gives the unique insights we need to establish authenticity.

Replica microscopes are always cut with industrial dies, often oversized in order to imitate a hand-made screw. Leeuwenhoek did not have such sophisticated equipment, and the threads of his screws were rolled. This method of manufacture displaces metal, rather than removing it. The SEM reveals the characteristic signs, notably the tendency for the crest of the thread to be grooved. Detritus within the root of the thread is further indicative of its provenance.

The same procedure was used in creating the newly-discovered silver microscope. Evidence of production can be discerned on the specimen pin, which features a softly faceted profile due to its being hand-forged. A replica pin would have been turned on a lathe, and the SEM will immediately display the characteristic signs of tooling.

Leeuwenhoek clearly wished his microscopes to be functional, rather than perfectly finished. Sometimes he decorated the main handle with

LEFT Replica Leeuwenhoek microscope of brass sold by the Boerhaave Museum, Leiden. It is a faithful copy of an authenticated instrument in their collections.

CENTRE The brass microscope found by amateur detectorists in mud dredged from a Delft canal, claimed to be one of the Leiden replicas. The SEM proved this wrong.

RIGHT A silver Leeuwenhoek microscope, discovered during a house clearance in East Anglia, in December 2023. It has much in common with the Delft instrument.

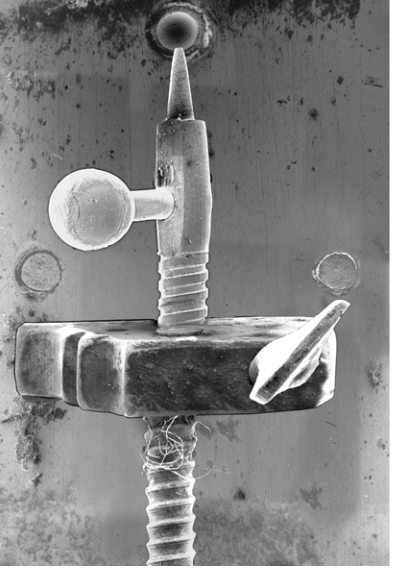
three perforations, and the edge profile of each of his microscope body plates is always polished and rounded, whereas the brass sheet of the replicas is always cut with shears, and has a sharp, angular cross-section. Similarly, the perforated handles Leeuwenhoek produced are thin and seem neatly punched and polished, whereas the replica handles are thicker, and are conspicuously machined with a countersunk drill-bit. Even though Leeuwenhoek took pains to add this decorative feature, he made little attempt to ensure consistency of design – no two are the same – and bilateral symmetry was never his aim. One of the characteristics of his microscopes is their lightness. I found that the original brass microscope, for example, weighs a mere 6.24 g, whereas the mass of the Boerhaave Museum replica, with which some confused it, weighs 14.71 g. Clearly Leeuwenhoek conserved his metals.

Finding more Leeuwenhoek

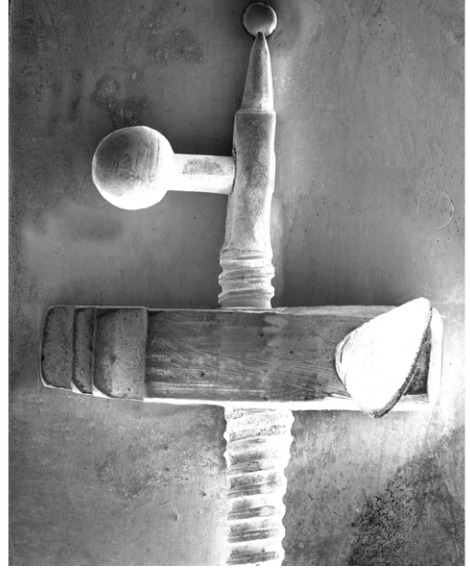
For more than two centuries it was accepted that no further examples of Leeuwenhoek microscopes would ever be found. When Haaxman wrote his

The recently discovered silver microscope under macrophotography at the Christie's studio (left) compared with the finished SEM study (right). Details of the main screw just visible to the naked eye can be discerned with diagnostic clarity under the high-resolution SEM image.

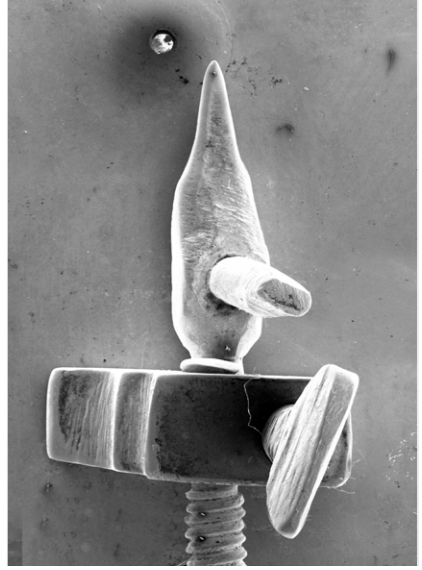
pioneering biography in 1875[10], the instruments were mentioned in the past tense, as if all were then known. The microscopes in Leeuwenhoek's possession that were left at his death were auctioned in 1747, after his daughter Maria had died. That was believed to be the last opportunity for further unknown examples to emerge. Dobell's master-work, published in 1932 to mark the tercentenary of Leeuwenhoek's birth, speaks of the remaining microscopes with no hint that any more might yet be found[11].



LEFT
The stage assembly of the replica brass Leeuwenhoek microscope under the SEM discloses the lathe-turned specimen pin, die-cut screw thread, and prominent riveting.



CENTRE
The recently-discovered authentic instrument from the Delft canal shows a hand-forged specimen pin, rolled screw thread, and near-invisible rivet heads that are finely polished.

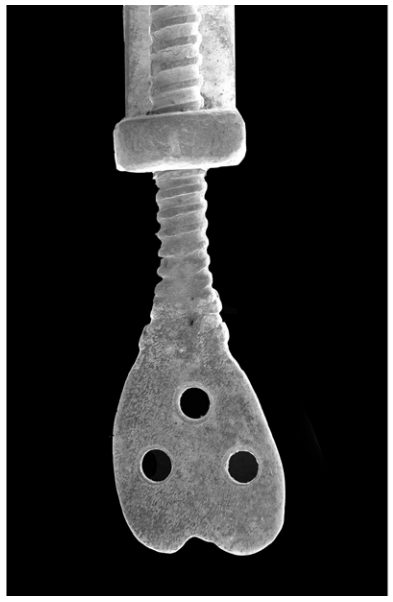


RIGHT
The specimen pin of Leeuwenhoek's silver microscope, first revealed in December 2023, has a softer profile due to the malleability of the metal, and is clearly hand-made.

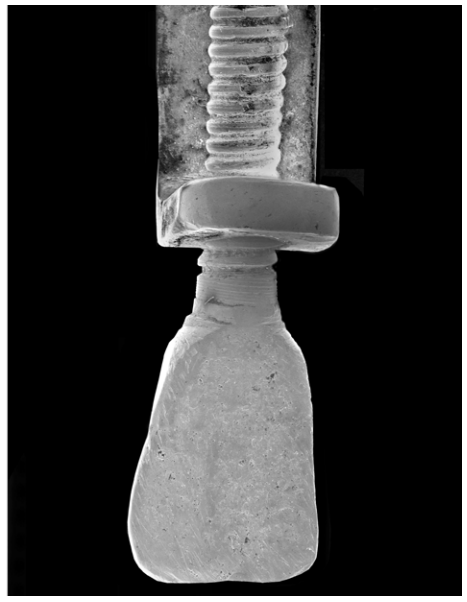
Since then, four previously unknown examples of his microscopes have emerged, three of which had passed through my hands. No scholar could have anticipated such a series of revelations. Clearly, unlikely as it seems, there may be others yet to emerge.

It proved to be the SEM that provided me with the means to establish a protocol by which these finds could be objectively authenticated. It would now be instructive to apply these findings to the remaining microscopes attributed to Leeuwenhoek, for the provenance of several is often weak, and their genuineness has been asserted by subjective opinion, rather than scientific facts. When I first learned of Antony van Leeuwenhoek when a schoolboy, there were nine known microscopes associated with his name. Today there are 13. But, were we to scrutinise them all with the guidance of the objective criteria that I have ascertained, several of those will prove to be copies or forgeries. Perhaps, at the end of all these proposed investigations, there may still be nine authentic Leeuwenhoek microscopes after all.

LEFT
Several of Leeuwenhoek's brass microscopes feature his decorative pattern of three perforations on the main handle. A countersink drill bit has been used on this replica.



CENTRE
Perforations in the handle of the authentic microscope were punched without a drill. The brass is also finer; a replica microscope weighs twice as much as a Leeuwenhoek original.



RIGHT
Leeuwenhoek needed the construction of his microscopes to be functional, rather than precise. The silver handle was beaten to shape, with little attempt to make it symmetrical.

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Brian J Ford has studied Leeuwenhoek for over forty years. He discovered his original specimens hidden in the archives of the Royal Society, investigated how they were prepared, and was the first to take micrographs of a Leeuwenhoek section through an original microscope. Professor Ford has published many hundreds of papers on microscopy, including 250 publications on Leeuwenhoek alone, and many of his books have been devoted to the microscope. He is a Fellow of Cardiff University, former Fellow of the Open University and Visiting Professor of Leicester University, and he is currently based at Cambridge.