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The Lab in the Museum

Or, Using New Scientific Instruments to Look at Old Scientific Instruments

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▾ **ABSTRACT** This paper explores the use of new scientific techniques to examine collections of historic scientific apparatus and other technological artefacts. One project under discussion uses interferometry to examine the history of lens development, while another uses X-ray fluorescence to discover the kinds of materials used to make early mathematical and astronomical instruments. These methods lead to surprising findings: instruments turn out to be fake, and lens makers turn out to have been adept at solving the riddle of aperture. Although exciting, in some ways this is neither novel nor particularly unusual. After all, lab techniques have been used in art and archaeological collections for a very long time. In fact, scientific instruments themselves have been examined in this way since at least the 1950s. What, then, is special about the use of new instruments to examine old instruments? We argue that the answer has less to do with measuring historical innovation or establishing priority, and more to do with networks of craft know-how that, typically, have left no other historical traces than those embodied in surviving instruments themselves. We show, in particular, how collections of objects can be mobilised within wider histories of knowledge, placing instruments within a dynamic interplay of craft knowledge, expertise, labour, commerce, and material exchange, over the *longue durée*. Finally, we suggest that these kinds of lab analyses can

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be given an extra dimension through the use of computational modelling, and we introduce the "Tools of Knowledge" project, which is designed to bring together XRF with techniques from the digital humanities, in order to tell a new story about the development of scientific instruments from the 16th to the 20th century.

▼ **KEYWORDS** Scientific Instruments, Museum Collections, Laboratory Analysis, Craft Communities
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Introduction

What is the relationship between historical collections of scientific and medical instruments, technological artefacts and scientific specimens, and the historiography of science?[1] More generally, how do artefacts that have persisted through time inform, determine, shape, or challenge our sense of historical time? The connection between history's physical remnants and historical writing is not altogether straightforward. On the one hand, the "material turn" in the humanities is not necessarily based on actual surviving materials: many of the finest studies in this vein deal with craft manuals, descriptions of substances and experiments, and other textual sources.[2] On the other hand, the complex histories of collections themselves pose challenges for historians: scientific instruments were first collected by museums in order to show the onward march of progress; survival biases also distort the historical record; and "showpieces" have been prioritised over everyday items and what Ad Maas calls "key pieces"—objects that derive their value less from their intrinsic qualities and more from the part that they play in significant scientific stories.[3] Another related problem is that the history of knowledge has rarely been conceived in terms of objects and their use. Not least, this is because the knowledge that objects embody through their design, form, and operation is often difficult to articulate and to integrate with traditional histories of the sciences.[4] To give just one example, consider the vast number and variety of early sundials in museum collections, as compared with the absolutely marginal status of sundials in histories of the sciences. As Jim Bennett has pointed out, much intellectual and artisanal energy was spent on the perfection and elaboration of this humble instrument in the early modern period.[5] As historical sources, not only do they illustrate the diffusion and integration into everyday life

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[1] On this relationship, see, in particular, van Helden & Hankins (1994); Bennett (2003); Mosley (2007); Taub (2009; 2011).

[2] See, for example, Long (1991).

[3] See Maas (2013). For the history of scientific collections see the 1995 special issue of the *Journal of the History of Collections* on this topic, especially A. Turner (1995) and Anderson (1995). For a fascinating discussion of how survival rates can affect and distort the historical record, see A. Turner (2003).

[4] For a sustained treatment of this topic, see Baird (2004).

[5] Bennett (2009).

of regularised concepts of time-keeping, but they also exist at the intersection of astronomy, geography, chronology, and practical geometry. Yet, within museums they are seen as something of an embarrassment, and they barely feature even in histories of the human relationship with time.[6]

One way to approach the relationship between scientific collections, knowledge, and time is to ask what is special about collections relevant to the history of science? First, we need to provide some demarcations. It should go without saying that historians of science have made extensive use of book and manuscript collections.[7] Then, the history of natural history has been profoundly shaped by historical collections, many early examples of which survive, now in national museums.[8] Recent studies—and several of the other contributions to this special issue—examine the ways in which biomedical specimens and living collections shape, determine, and even distort scientific study.[9] This leaves history of science collections proper: that is, scientific materials brought together into museum collections with the specific intent of illustrating the development of natural knowledge.[10] The best known of these are held at specialist institutions like the Museo Galileo in Florence, the Deutsches Museum in Munich, and the Science Museum in London. Many significant collections have also coalesced and formed into museums at universities—for example at Oxford and Cambridge. These are the classic collections of historical scientific and medical instruments—though one final caveat must be given, that the national collections formed around 1900 were typically intended to illustrate science *and industry*, and in fact the latter category is often dominant.

Now we can ask the question with more specificity: what is special about collections of historical scientific instruments? The most obvious answer is revealing: these collections largely comprise instruments that were once cutting edge at performing highly specialised tasks, mainly involving measurement, observation, and/or demonstration. And even when these tools became standardised and widespread, they were still used for very particular purposes. This means that in many cases we can still *use* early instruments, and therefore intervene in the natural world with old tools. We can examine long-dead spiders under microscopes made around 1700. We can look at the stars with even earlier telescopes. With enough conservation work and care we can reconstruct 19th-century electrical demonstrations. Using early sundials is particularly easy. This has resulted in two important contributions to historical understanding—one well known and the other less so. The first is historical reconstruction

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[6] There is little or no discussion of sundials in, for instance, Poole & Williams (2019); Champion (2017). A recent work that integrates a history of horology/temporality with sundials is Desborough (2019).

[7] For an overview, see Frasca-Spada & Jardine (2000).

[8] For a history of the materials of natural history, see Findlen & Toledano (2018). For a project that emerges directly from engagement with surviving specimens, see the "Mobile Museum" project based at the Royal Botanic Gardens, Kew and Royal Holloway University (https://royalholloway.ac.uk/research-and-teaching/departments-and-schools/geography/research/explore-our-research/the-mobile-museum-economic-botany-in-circulation/).

[9] Kowal, Radin, & Reardon (2013).

[10] Here we are following Bedini (1965, p. 1): "a science museum is defined as a repository for the preservation and exhibition of collections relating specifically to the physical sciences and technology."

or re-enactment. There is now a reasonably large literature and an ongoing series of projects involved in the replication of historic experiments and techniques.[11] It is the purpose of our paper to survey a second, less studied kind of direct engagement with historical scientific instruments: the analysis of earlier instruments using newer scientific instruments. X-ray machines have been used to analyse early astrolabes; interferometers have been used to analyse telescope and microscope lenses; and micrometers have been used to analyse divided scales. This is not a particularly well-known practice, though it draws on expertise and experiences in the broader museum and gallery, art historical and archaeological worlds, and there scientific analysis is naturally a far greater concern than it has been in the smaller field of history of science.[12]

Although this has obvious affinities with scientific methods in archaeology and art history, there is in fact a separate genealogy of "the lab in the museum" specific to instrument history itself. We propose that the scientific study of early scientific instruments emerged from two distinct strands, one having to do with the fundamental scientific practice of calibration, and the other, much later, from curatorial questions having to do with authenticity and provenance. The body of the paper is divided into discussions of these two separate but intersecting histories. We then propose a third, much newer paradigm, which, while drawing on the techniques and lessons of these earlier enterprises, combines them with recent efforts in science studies to understand past communities and networks of craft practitioners. In our conclusion, we describe some recent trends in this work and introduce the "Tools of Knowledge" project, which seeks to combine lab techniques with data analysis to provide a new *longue durée* history of the materials of scientific practice. Here, questions of temporality and historical knowledge are brought to the fore. We argue that—from its origins in calibration and antiquarianism—scientific analysis of large numbers of instruments presents both new *kinds* and *durations* of historical explanation. We are on the cusp of a wholly new use for collections of historical technologies and instrumentation, in which these artefacts speak not of isolated experiments, discoveries, and innovations but of long-term patterns and trends in the circulation of raw materials, craft know-how, and embodied expertise.

From Calibration to Performance

Calibration of instruments is one of the most fundamental of scientific activities.[13] All use of measurement devices presupposes some standard of calibration.[14] Clocks have been checked against sundials, scales against other scales, temperature measures

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[11] See, for instance, Heering & Wittje (2011); Fors, Principe, & Sibum (2016).

[12] To our knowledge there is no specific history of scientific techniques in art history, archaeology, or conservation. One recent work of Science and Technology Studies (STS) stands out for contemporary interest in this area: Rubio (2020).

[13] For an exemplary overview, see Tal (2017).

[14] On the historiography of measurement, see Gooday (2004, pp. 1–39).

against physical phenomena such as freezing and boiling points. As Eran Tal points out, for even quite simple scientific instruments to work at all there needs to be an entire infrastructure of calibration processes in place, involving laboratories dedicated entirely to the process of standardisation.[15] In the philosophy of science, calibration has been key to questions of the scientific method, mobilised in defence of both realist and relativist positions.[16]

All acts of calibration are, in a weak sense, historical, in that new instruments are checked against old. But a more substantial historical sensibility develops (and the relationship between past and present is inverted) when the practice of calibration turns to an interest in the *performance* of earlier instruments. This is not such a disjunction as it might seem: calibration is always a two-way check, even when trust is placed in the device that is chronologically prior. When a new instrument is found to be faulty, attention naturally turns to the reliability of the standard against which it has been measured, and this in turn is tested in case it is malfunctioning, has become distorted or damaged, or has not been operated properly.[17] From here it is only a short step to the properly historical consideration of past standards. This is most dramatically evident in the extensive and well-documented histories written by those charged with the establishment of new standards of measurement. W. H. Miller's substantial account of *The Construction of the New Imperial Standard Pounds* of 1856, for example, begins with a history of English standards of weight going back to Saxon times; this then segues into Miller's methodological discussion, followed by his assessment of surviving earlier measures themselves.[18] Here the legal, material, and physical analyses of specific objects overlap fully and it is not possible to decide whether the record of a date on which a measurement was taken is part of the scientific or historical record.

Precision measurement itself provides one exemplar of the genealogy we wish to tell—Allan Chapman, for instance, has examined the development of scale-engraving as a history of precision—but in fact the most instructive example of calibration turning to historical study is to be found in the history of optical instruments.[19] Here the issue is acute: when new celestial phenomena or organisms or structures are observed, these observations need to be repeated by other people using other instruments.[20]

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[15] Tal (2017, p. 33).

[16] This is a large topic, perhaps best understood as a subset of the general topic of "bootstrapping" in philosophy of science. For an instrumentally mediated introduction, see Hacking (1983, pp. 233–245).

[17] This is touched on or analysed directly in many of the case studies in Collins & Pinch (1993).

[18] W. H. Miller (1856). On the inherent historicity of the establishment of standards, see, for example, Schaffer (1997); Jardine (2019a). For a more recent example of an investigation into historical standards using the re-measurement of surviving artefacts, see Connor & Simpson (2004, pp. 407–612).

[19] Chapman (1983). We should acknowledge here that "calibration" is being used in the broad sense of checking one instrument against another. It is, properly speaking, the observation that is being calibrated when the images produced by two microscopes are compared. The more restricted sense (and etymology, back to the "calibre" of a gun) is limited to measurement—though in questions of magnification, micrometry, and resolution these, too, are important in optical instrumentation.

[20] Hence the centrality of the microscope to the philosophical debate, at least since Hacking (1983).

Perhaps the most famous early case of optical replicability is that of Antoni van Leeuwenhoek (1632–1723), well known as the first to observe microorganisms and as the discoverer of many microscopic structures and phenomena. The shock of Leeuwenhoek's work, arriving more or less unannounced on the desk of Henry Oldenburg in the 1670s, led to a complex negotiation over Leeuwenhoek's legitimacy as an observer, a situation made worse by the fact the Leeuwenhoek never revealed how it was that he had made his famous high-power lenses.[21] It is possible to identify four strands to the establishment of his credentials: first, he was vouched for by respected members of the community; second, he communicated his findings accompanied by carefully prepared illustrations; third, he established standards of microscopic measurement, for instance by using human hair as a reference; fourth, he sent finished microscopes complete with prepared specimens to the Royal Society for direct analysis.[22] But the question of Leeuwenhoek's lenses and how they were made has persisted up to the present day.

Shortly after his death in 1723, the Royal Society acquired 26 of Leeuwenhoek's microscopes, which were described in the *Philosophical Transactions* by Martin Folkes.[23] Folkes's aim was to describe the collection, and his comments on the optical quality of Leeuwenhoek's lenses are limited (though he mentions a "Tryal"). Folkes does, however, attempt a basic comparison of Leeuwenhoek's specimens, by observing his own preparations alongside Leeuwenhoek's. This is significant, as too often the history of microscopy is told in terms of lens-manufacture, when specimen preparation and microtechnique are also essential parts of any successful observation.

A far more substantial analysis of Leeuwenhoek's Royal Society instruments was prepared 15 years later by the microscopist Henry Baker.[24] (Sadly the Society subsequently lost all 26 microscopes, making Baker's the last such analysis.[25]) Unlike Folkes, Baker attempted to establish the focal distances and magnifying power of Leeuwenhoek's lenses, using an inch scale divided into 100 parts. Baker concluded that the microscopes in possession of the Royal Society could not have been Leeuwenhoek's most powerful, as they would not offer sufficient magnification to examine the smallest structures described in Leeuwenhoek's letters. (Note that Baker does not therefore question Leeuwenhoek's authority, or the veracity of his observations.) Baker's aim, like Folkes's, was to provide an account of some important objects in the Society's possession; it was also, as the second half of the paper makes clear, intended as a promotion of a new microscope (supposedly) even more powerful than Leeuwenhoek's, made by the optician John Cuff for Folkes, and described in Baker's *The Microscope Made Easy*. Here, questions of calibration sit alongside matters of historical and commercial interest.

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[21] There is an extensive literature on Leeuwenhoek; this account was prepared with reference (in addition to subsequent citations) to Ford (1981); Fransen (2019); Zuidervaart & Anderson (2016).

[22] This, incidentally, illustrates the fact that far more than simple instrumental performance is required for any act of calibration, replication, or verification; see Gooday (2004, p. 11).

[23] Folkes (1722–1723).

[24] Baker (1739–1740).

[25] Robertson (2015, p. 4).

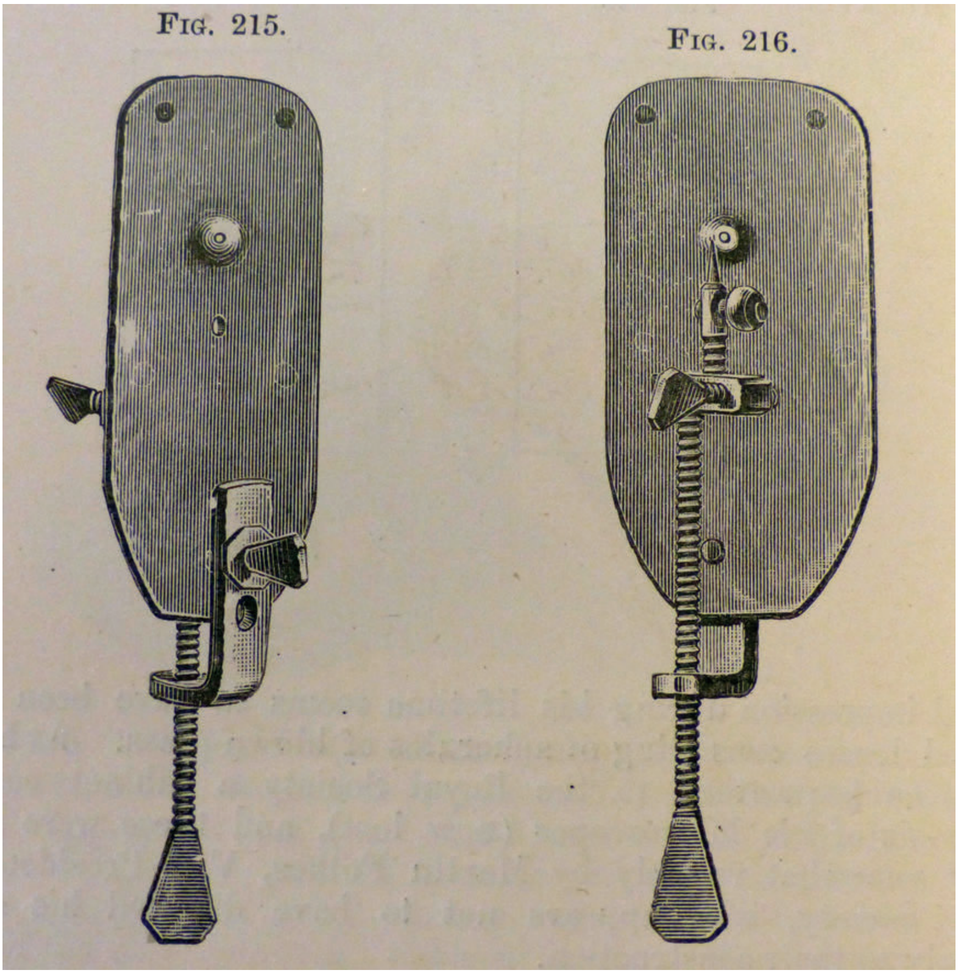

Figure 1. John Mayall's drawing of a "Leeuwenhoek" microscope. From "Leeuwenhoek's Microscopes" by J. Mayall (1886), *Journal of the Royal Microscopical Society*, *6*, p. 1048. Reproduced with permission of the Whipple Library, Cambridge, UK.

Because of the mystery surrounding Leeuwenhoek's technique of lens manufacture, and the fact that the optical performance he achieved was not (whatever Baker would claim) matched until the 19th century, his microscopes have attracted enormous amounts of attention since Baker was writing in the 1730s, and indeed Baker can be seen as inaugurating not only the technical study of Leeuwenhoek's lenses, but also the technical analysis of historical instrumentation. In the 19th century, when many of the theoretical aspects of optical performance were resolved, the true magnitude of Leeuwenhoek's achievement came to be understood, and by the early

20th century he was hailed as “the Father of Protozoology and Bacteriology” and celebrated in a number of biographies and historical studies.[26]

The 19th-century studies culminated in John Mayall's remarkable attempt to replicate Leeuwenhoek's microscopes, based on a close study of Utrecht University's extremely powerful instrument (see Figure 1).[27] Mayall pointed out that during Leeuwenhoek's lifetime it was understood that he used a method of glassworking that resulted in spherical lenses—but that subsequently Baker and others had revealed that Leeuwenhoek's lenses were in fact extremely finely ground bi-convex lenses.[28] This is an important detail, as we will see below. Following Mayall's work, increasingly accurate assessments of Leeuwenhoek's lenses—their magnification and especially resolving power—were carried out by Pieter Hendrik van Cittert, Maria Rooseboom, and Pieter Van Der Star.[29] The details of these examinations are less important than the historiographic trend of which they are part. We characterise this as “antiquarianism”: a dedication to the exact reconstruction of the past as a set of material facts.[30] Although it is often viewed negatively, antiquarianism is in fact a rather unusual and provocative discipline—though offering a defence of its methods is beyond our scope.[31] The antiquarian conception of the past as a set of material remains, its interdisciplinarity and openness to scientific methods, and its exacting standards of accuracy are all central to instrument studies, as well as to curatorial expertise and studies of material culture more generally.

But antiquarianism is very far from most recent historical research, and this is evident in the fate of the optical researches that we have been discussing. An illustration of this is Gerard Turner's 1967 essay “The Microscope as a Technical Frontier in Science,” which opens “If there is such a thing as progress, then, surely it is manifested by increasing accuracy of measurement.”[32] The point is not to dispute this claim, but rather to insist upon the fact that, as we saw with Leeuwenhoek, accuracy is only one part—and indeed only has meaning as a part—of a much larger socio-technical system. Intriguingly, Turner's intention was to provide a metric against which the history of science could itself be calibrated:

> With the establishment of [a graph optical capability against date of manufacture], it becomes possible to assess discovery in a new way. If certain resolution produced by the manufacturers is closely followed by a discovery requiring that degree of resolution, then the research is keeping pace with the instrument.[33]

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[26] Dobbell (1932).

[27] See Hyslop (2008).

[28] Mayall (1886).

[29] Van Der Star (1953) is by far the most detailed and summarises previous work.

[30] Another salient example from the history of science is the analysis and use of three telescope lenses presented to the Royal Society by Christiaan Huygens in 1691. See Higgitt (2019, pp. 474–475).

[31] The classic study of antiquarianism is Momigliano (1950). For an overview, see P. N. Miller (2017). For a provocative analysis, see Berger (2016).

[32] G. L. Turner (1967, p. 175).

[33] G. L. Turner (1967, p. 177).

This completes the move from calibration within science to calibration within the history of science. Historical time is itself indexed against technical development, and so collections act to calibrate history. Within the agenda of antiquarianism this makes perfect sense: historical change, considered as evolutionary progress, is modelled through the comparison of historical events against scientifically analysed material remnants.

But this is only one side of "the lab in the museum," the other being the curatorial treatment of large numbers of instruments. Like the move from calibration to antiquarianism we see a trajectory here too, and in fact we might describe it as going *from* antiquarianism to the historical anthropology of the workshop. The pivot between these two genealogies is the mid-20th century, and the institutional and professional contexts are the museum and the curator. The antiquarianism that motivated studies of the performance of instruments can also be seen in the close attention to large groups of objects now collected together in museums like the Whipple in Cambridge, the Museum for the History of Science in Oxford, and the Adler Planetarium in Chicago—not to mention the national museums in London, Edinburgh, and other metropolitan centres around the world. Cataloguing, indexing, and organising these collections was not in and of itself at odds with the kinds of analyses and conclusions we have seen—and in fact many of the studies cited so far originated precisely in such curatorial contexts. Yet this second kind of laboratory work is distinct both in its paradigmatic instrument—not the microscope but the astrolabe—and in its scope and results.

Analytical Laboratory Techniques in the Science Museum

For modern historians of science, the antiquarian paradigm can be consigned to its own historical era, and is of relatively little use in answering the kinds of questions now raised within the discipline, which have more to do with the construction and circulation of knowledge than the precise timing of moments of discovery and breakthrough. Of greater and more immediate relevance is a distinct strand of scientific work that travels in the opposite direction—that is, from antiquarianism towards a deep historical understanding of instruments within the specific contexts of their time and place, which we might almost see as a kind of historical anthropology, so close is its attention to the individual working practices of small artisanal communities. This work emerged from curatorial practice around the mid-20th century—indeed, the analytical laboratory's entry into the science museum can be dated with some precision.

In mid-August 1951, a young historian named Derek Price contacted a colleague at the University of Cambridge's Cavendish Laboratory to ask a favour.[34] Price himself had recently arrived at Cambridge to study under Rupert Hall, curator of the newly established Whipple Museum of the History of Science. Price's project,

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[34] A. A. Moss to D. J. Price [Letter] (1951, Aug. 15), D 076, Whipple Museum Archives, Cambridge, UK.

entitled "The History of Scientific Instrument Making," involved the close analysis of a large collection of historic instruments that had recently been donated to the University by a local private collector.[35] It was, as such, a piece of work almost entirely without precedent. As Hall would later reminisce, both he and Price, "like the whole population of Britain, save a few score of individuals, … began with a total ignorance concerning the scientific instruments of the period from the sixteenth to the early nineteenth centuries."[36] This left the exact role played by scientific instruments in the development of science as a more-or-less open question; and it established a new tension between the traditional antiquarianism of instrument collecting and the research interests of the emerging field of the history of science. For Price's purpose the Whipple collection needed to be much more than an array of individually compelling antiques—it needed to form a sound and coherent dataset that, as a whole, might be taken to represent an accurate record of the material culture of science. Instruments were now evidence, and so needed to be trustworthy. It was here that Price's friend at the Cavendish came into play.

Price appears to have quickly developed some scepticism towards the authenticity of several pieces in the Whipple Museum's collection. Hall had flagged up one astrolabe, in particular, as possibly a fake, and from this tip-off Price quickly pursued several lines of inquiry to investigate the veracity of it and similar suspect pieces.[37] Price himself had a background in metallurgy as well as links with the university's physics department, and so it was perhaps not much of an investigative leap to ask the metallurgist A. A. Moss to subject several instruments to chemical analysis by spark spectroscopy. The results were unambiguous: two ostensibly 16th-century instruments were immediately identifiable as forgeries from their anomalous metal composition, which matched modern, electrolytically manufactured copper sheet and lacked the tell-tale impurities typical to early modern open-hearth metals. From this crucial lead Price was able to pursue several corroborating strands of evidence and soon uncovered a wealth of further fakes: five in total at the Whipple, as well as similar examples in public collections in Rotterdam, Leiden, Munich, Utrecht, Prague, Nuremberg, Edinburgh, and Greenwich.[38] All of these pieces could be traced back to a single source, the dealership Frederik Muller & Co. (under the direction of the collector and dealer Anton Mensing), two of whose sales, in 1911 and 1924, seemed to be linked to all of the forgeries that Price had unearthed.[39] Given the "exceptional workmanship" that characterised the more than 30 "Mensing fakes" that he ultimately identified, Price singled out the novel application of laboratory techniques as crucial to his hunt:

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[35] Falk (2014, pp. 114–115).

[36] Hall (2006, p. 59).

[37] Jardine (2019b, pp. 201–221).

[38] Price (1958). Both suspect instruments at the National Maritime Museum, Greenwich, were also subjected to spectroscopic analysis, and their copper was found to "agree [with the Cambridge data] in showing Zinc to be undetectable and Silver present only as a trace considerably smaller than 0.01% found in genuine [16th-century] copper" (p. 393).

[39] On the "Mensing fakes," see also De Clerq (2000); Johnston, Mörzer Bruyns, Deiman, & Hooijmaijers (2003).

> If the faker had secretly dispersed his products or if he had not made the fatal error of using modern electrolytically-manufactured copper sheet instead of ancient open-hearth metal (a difference readily detected by the spectroscope) it might have been impossible to prove conclusively that the evidence of a whole series of instruments must be rejected.[40]

Price's work stands as a turning point in the study of scientific material culture. The “Mensing fakes” were the first historic instruments to be publicly outed as forgeries, helping to establish the value of laboratory methods in Price's small but rapidly growing field. While the tools of the forensic lab had previously been applied in the exposing of *literary* frauds connected with the sciences—most notably the Blaise Pascal Forgeries of 1867—they had not previously been applied to the antiquarian concerns of the scientific collector or museum.[41] As one of the present authors has already argued elsewhere, Price's manoeuvre—the application of present science to past science—must be understood within the context of its disciplinary moment.[42] The middle of the 20th century saw significant changes in the ways that collections were organised and studied, transforming the relationship between individual objects and an aggregated, data-driven way of knowing. As mentioned above, Price was unusual in eschewing antiquarian concerns with the individual masterpiece in favour of studying a large corpus of instruments; he was also, therefore, moving away from a theory-driven “Great Man” style of history in pursuit of a then almost totally unknown history of craft know-how—or, as he put it, a “continuous thread” of “understanding the world through tangible technical devices.”[43]

His technique, therefore, was novel in two quite distinct and seemingly contradictory ways. On the one hand, Price was a pioneer of a thoroughly positivist “science of science”: through the aggregation of large datasets, he argued, science could be turned on itself to represent and assess its own development over time—and even make projections into the future.[44] Yet, on the other hand, Price's main concern in his work on instruments appears to us now as something quite like the opposite of this positivist “scientism,” namely, the *longue durée* history of artisanal skill. So we can begin to see here the important inversion that occurred between the practices of calibration discussed in our previous section and these new practices of provenance pioneered by Price. Whereas the scholars of Leeuwenhoek had sought to define his instruments in terms of their *scientific* reliability, Price now used scientific methods to help determine the *historical* reliability of a whole swathe of instruments preserved in major public collections.

Exemplary is the foundational instrument for Price's data-driven approach: the portable two-dimensional representation of the heavens called the astrolabe

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[40] Price (1958, p. 393).

[41] The ink on the dubious letters presented by Michel Chasles to the Academie des sciences was subjected to chemical testing, but this analysis appears not to have significantly impacted the protracted debates over their authenticity: Higgitt (2003, p. 439).

[42] Jardine (2019b).

[43] Price (1980, p. 76).

[44] Jardine (2019b, p. 215).

Figure 2. Astrolabe, signed "Ioannes Bos/1597/Die 24 Martii," acquired by R. S. Whipple from a dealer in Paris in 1928 and later revealed to be a forgery. Wh.0305, Whipple Museum, Cambridge, UK. Reproduced with permission.

(See Figure 2). No type of scientific instrument has been more closely studied or more rigorously analysed than this astronomical calculating device. And it is easy to see why. Astrolabes were an ideal case study for Price's purpose, insofar as a relatively large number of them survive (owing to both their beauty and their robustness), comprising a corpus that both spans an extremely long period of time and covers a very extensive geographical distribution. Early in Price's time at Cambridge he began to focus on the astrolabe, compiling a large "International Checklist" of the instrument published in two parts in 1955.[45] Like his coeval work on the "Mensing forgeries," Price's work here was both comparative and analytical. As he had done when chasing down the forgeries, Price took advantage of new forms of inter-collection media to make his research possible. It was only from the mid-20th century that major science collections began to be published in comprehensive catalogues, making it feasible for him to consult public listings across numerous institutions in order to agglomerate the near-exhaustive "Checklist," which ultimately included information on around 700 astrolabes known to survive in public and private collections. But Price also brought the lab to bear on specific exemplary specimens, most strikingly his triumphant discovery in Peterhouse College Library of a previously overlooked manuscript on the equatorium—a large astrolabe-like instrument—that Price attributed to Geoffrey Chaucer. Price not only had the Cavendish Laboratory make a full-scale replica of this instrument, but he also had the manuscript itself analysed using the Cavendish's infrared and ultraviolet photographic equipment to reveal words that had been erased and overwritten.[46]

So at the same time that mainstream history of science began to cement its identity as a field interested in past scientific practice, a small cohort of instrument specialists began to apply analytical techniques to further explore the worlds of artisanal labour and craft skill that underpinned the sciences' hands-on aspects. The central questions being asked here were not so much about authenticity as they were about specific working practices at particular sites. When applied to instruments whose dating was already secured, the tools of the lab could be wielded to reveal entirely new insights into such things as metal production methods and metalworking techniques. Here, a considerable debt must be acknowledged to the sub-discipline of archaeometallurgy, which by the 1970s had already established itself as a vibrant field of study.[47] Indeed, by the 1980s we begin to see practitioners trained in this discipline's techniques moving across to assess instruments like astrolabes. Yale archaeometallurgist Robert B. Gordon, for example, conducted an exemplary assessment of two 16th-century German astrolabes using micrographic analysis, micrometric measurements, close inspection of tooling marks, and electron microprobe testing of alloy composition. With scant few written records of workshop practices surviving to us, Gordon's study offered a strikingly novel account of artisanal labour in the workshop of the Nuremberg maker Georg Hartman. Gordon was explicit in the transfer of skills here—he described his work as "an introductory study intended to show methods of examination that reveal manufacturing techniques."[48]

Gordon's work was microhistory *par excellence*. His conclusions reached down to the level of the specific tools used and the exact division of labour employed in the manufacture of a single instrument. When combined with assessments of design

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[45] Price (1956). Price's survey built upon the foundational work in Gunther (1932). Because all astrolabes are unique, Price was able to introduce a numbering system for the identification of known specimens.

[46] Falk (2014, p. 117). Recent analysis has rejected the Chaucerian authorship in favour of the Benedictine monk John Westwyk: Rand (2015).

[47] Rehren & Pernicka (2008).

[48] Gordon (1987, p. 71). See also Gordon (1986).

and scale-division accuracy, such evidence could begin to elucidate the relationship between mathematical practice, artisanal skill, and market economics in the early modern instrument trade, on a local level at least.[49] The introduction of new non-invasive analytical techniques proved particularly fruitful for this kind of close study. Work conducted on the Antikythera mechanism stands out in this regard. As no similar objects are known and no historical sources survive to describe this ancient Greek astronomical device, researchers have been particularly reliant on enhanced imaging techniques to assist in the painstaking job of reconstructing the complex gearwork inside the mechanism.[50]

But work on astrolabes has in many respects remained the gold standard for such analytical microhistory. Work at the turn of the millennium at the Adler Planetarium in Chicago, Illinois, offers one choice example. Here, an interdisciplinary team of astrolabe researchers and metallurgists subjected a small cohort of instruments to cutting-edge non-invasive synchrotron radiation techniques. X-ray fluorescence (XRF) analysis now replaced the kinds of emission spectroscopy that Price had used, enabling the accurate determination of elemental composition of metals without sacrificing materials from the target artefact. Likewise, transmission X-ray diffraction and scanning radiography could now reveal the internal microstructure and thickness of metal artefacts in an entirely non-destructive manner. Preliminary findings extended the range of evidence that could be brought to bear on questions of authenticity. XRF assessment of two near-identical astrolabes held by the Adler and Harvard—both suspiciously carrying the exact same signature as the Whipple's "Mensing" fake, "Ioannes Bos/24 March 1597" (see Figure. 2)—readily distinguished between the pure copper used in Harvard's example from the low-zinc brass used in the Adler's. But it was the diffraction and radiography evidence that offered novel insights into the specific working techniques of the artisans involved in the production of both of these artefacts. The Harvard instrument's mater, it was shown, had been made from mechanically rolled copper sheet while its rete had been cast, whereas in the Adler's astrolabe both these parts were shown to have been made from hand-hammered brass sheet. As is so often the case, no single piece of evidence definitively secured the dating or authenticity of an instrument. But, when taken together and combined with traditional curatorial inspection, the Adler team could conclude with confidence that the Harvard instrument was a forgery of a piece with the European examples that Price had already identified, whereas the Adler's instrument was a genuine 16th-century artefact—and as such was the pattern instrument from which the forgeries had been copied.[51]

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[49] Chapman (1983); Lamprey (1997); King & Turner (1994). The term "microhistory" is used here in Carlo Ginzburg's sense, as the close study of otherwise little-known actors, as a means to ask larger questions about communities and their historical contexts: Ginzburg (1993).

[50] A useful overview of the long history of research into the mechanism is given in Freeth (2015). Literature on the mechanism is far too extensive to cite in full here. A complete bibliography can be found at Antikythera Mechanism Research Project (n.d.).

[51] Stephenson, Stephenson, & Haeffner (2001). The difference in size between the original and the various copies can be attributed to the forger having worked from a photograph rather than the original object itself. As with the

At the time when they began their work, the Adler team were employing an extremely rare and expensive instrument; in 1998 there were only around 30 active synchrotron radiation sources in the world.[52] But the pattern of work that they established evinced the utility of non-invasive laboratory techniques, some of which could be pursued with somewhat less elaborate instrumentation. Certainly, XRF analysis can now be done to a good degree of accuracy using hand-held devices that are common to any metallurgical or archaeological laboratory. As the Adler team have noted, these relatively affordable machines can give very comparable results to their own synchrotron analyses; and even if hand-held XRF instrumentation comes with the significant drawback of only allowing surface analyses, they also come with the advantage that they are much easier and quicker to use.[53] Astrolabes continue to be a particular focus of this kind of study, either to authenticate new finds—such as the Portuguese mariner's astrolabe recently recovered from the Sodré wreck-site—or to secure metallurgical evidence in support of deep historical analyses of individual instruments.[54] A notable pioneer in the latter is John Davis, who has deployed his own hand-held XRF machine as part of a range of rich and detailed studies into the origins of several medieval English astrolabes.[55] Indeed, the extent of Davis's work and other recent XRF analyses of similar instruments has begun to allow cross-comparative assessment of types of astrolabe and their metalwork, and with it help untangle thorny questions of date and authenticity.[56]

What these close microhistorical studies all share is their deep focus on the materiality of the artefact. It is a technique that typically combines the close analysis of an instrument's structure and material properties with an assessment of the artisanal practices that might be recoverable through the use of laboratory techniques. But such depth of analysis naturally comes at the expense of breadth—most notably in terms of historical geography. Close study might reveal how a specific instrument was made and offer plausible accounts of the artisans who made it, but it tends to do so either in isolation (as with, for example, the Antikythera Mechanism), or within tight communities of practitioners and users (as with, for example, medieval English astrolabes). To step back from the workshop bench and take a broader view of instrument manufacture required scholars to study across geographical space and over time so that broader networks of material exchange and use might be brought into view. Here, the tools of the lab need to be applied in a different way. Price, of course, had already identified a data-driven model for this kind of work. But his

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various other "Mensing fakes," it is assumed that the forger had access to nothing more than the photographs that were included in the sales catalogues issued by Frederik Muller & Co. for their 1911 and 1924 auctions. For more on this, see De Clerq (2000).

[52] This number is an estimate based on data provided in the Wikipedia article "List of Synchrotron Radiation Facilities" (2021).

[53] Notis, Newbury, Stephenson, & Stephenson (2013).

[54] Mearns, Warnett, & Williams (2019).

[55] Davis & Lowne (2015); Davis (2017; 2019).

[56] See, for example, the table of XRF data in Davis & Schechner (2018, p. 14), which includes data from instruments at Harvard, Utrecht, Cambridge, Oxford, and the British Museum. Similarly, see Davis et al. (2020, p. 18).

positivist rendering of normative claims from accumulated data has quite reasonably fallen out of fashion among historians of science. For a better model we need to look instead to what laboratory techniques might be able to teach us about *craft communities* and *commodity exchange*. And the lab in the museum can only begin to illuminate these facets of the instrument trade when applied to objects en masse.

As difficult as it can be to apply analytical techniques to a large cohort of artefacts, some examples are to hand in the world of instrument studies. We have already mentioned that John Davis's work on medieval European astrolabes is beginning to build a corpus of data capable of revealing wider trends. XRF, Davis and Lowne have noted, "provides a valuable 'first look' at the major constituents of the 'brass' alloys (copper, zinc, tin, and lead) which in itself can reveal something about origins of a device."[57] As archaeometallurgists and industrial heritage researchers have known for some time, the relative proportions of these primary constituent metals can help narrow down both a date and a geographical location for the source brass used in an artefact's manufacture. And the detection of secondary, trace elements such as iron, arsenic, silver, and nickel can further act as markers of an alloy's vintage and place of origin.[58] But such evidence is rarely definitive and is almost always relative. Alloy composition might help bound the dates of an artefact or suggest a plausible origin point (perhaps as large as a continent or region), but an absence of hard-and-fast rules means that the surest method is to compare across a large corpus of data, ideally drawn from objects with secure provenance. And so Davis and Lowne remind us that the confident dating and placing of scientific instruments from XRF data will only be plausible "when a large enough database of results has been established."[59]

One case study in particular indicates the significant potential for such a project. For this we return to the work of the interdisciplinary research team centred on the Alder Planetarium in Chicago. Following their work on the Bos instruments, this group used their time with the synchrotron radiation source to analyse a wider range of the Adler's astrolabes. In a group of 24 European and Islamic instruments dated between 1350 and 1720, non-destructive X-ray techniques revealed one particularly striking pattern. A group of six astrolabes known to have been produced in Lahore between 1601 and 1662 were found to exhibit a quite distinct composition of high-zinc brass.[60] This, the group concluded, was the earliest evidence for systematic use of so-called "$\alpha + \beta$ brass," a high-quality form of brass manufactured by co-melting metallic copper and zinc (rather than by the more traditional cementation process of heating copper with calamine, a zinc ore). This was an advanced brass-making technology "previously believed to have been developed on an industrial scale in the nineteenth century in Europe"—but their analysis now evidenced its "use in Lahore on an industrial scale as early as AD 1601."[61] In addition to providing a new analytical tool for identifying instruments of likely North Indian origin, the team's conclusions

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[57] Davis & Lowne (2015, p. 279).

[58] Pollard & Heron (1996, pp. 196–238).

[59] Davis & Lowne (2015, p. 279).

[60] Newbury et al. (2004).

[61] Newbury, Notis, Stephenson, Cargill, & Stephenson (2006, p. 201).

Figure 3. "Circles of proportion," a circular logarithmic scale by Elias Allen to the design of William Oughtred, English, ca. 1635. As with a number of Allen's instruments, XRF analysis of this object reveals a very high level of zinc in its brass alloy—in excess of 35%—an amount at the very upper limits achievable in the traditional "cementation" process of brass manufacture. How this brass was made, and where Allen sourced it from, remain open questions that cannot be answered without a much wider assessment of the brass used in the manufacture of 16th- and 17th-century European instruments. Wh.0833, Whipple Museum, Cambridge, UK. Reproduced with permission.

raise a host of important questions relating to the historical geography of a "modern" brass industry—not least concerning the eventual transfer of the advanced skills used in Lahore to Western Europe. When, it becomes important to know, did European metalworkers "catch up" with Lahore and begin to produce (or import from the East?) pure zinc for co-melting with copper? Claimed dates for the introduction of this "direct" process of brass manufacture into Europe now range from the mid-17th century to the early 19th century, and the use of zinc levels as part of a reliable dating technique for European instruments will not be feasible until a large enough corpus of XRF data to narrow down this window has been collected (see Figure 3).[62] Such a corpus may then reveal new insights into the craft communities that made and worked with brass, and the exchange of raw and manufactured metal commodities across time and on a global scale.

Materials, Labour, and Expertise in Transit

This move, towards thinking about the circulation of materials and expertise, is also (and perhaps surprisingly) reflected in the latest work on Leeuwenhoek's lenses, which as we saw had previously been a paradigm for researchers interested precisely in lone genius craftsmen working in isolation. Earlier we presented a genealogy of the scientific analysis of instruments, which we traced to early interest in Leeuwenhoek's lenses. In fact, if we bring that story up to date we can learn an important lesson about the future of this kind of analytic study of material culture. The most recent study of Leeuwenhoek's lenses—in a project led by curator Tiemen Cocquyt, collaborating with scientists at the Technische Universiteit Delft—has examined two of Leeuwenhoek's microscopes using a technique called neutron tomography.[63] This process is analogous to X-ray, except that as neutrons are uncharged they pass through metal and allow a three-dimensional reconstruction of a whole Leeuwenhoek microscope. This is significant because one of the main hindrances to studying Leeuwenhoek's lenses has always been the fact that only a tiny portion of the lens of each microscope can be seen through the tight apertures on either side—the apertures are often under 1 mm and the entire lens might be as big as 3 mm in diameter. The question of the overall shape and nature of Leeuwenhoek's lenses has therefore never been settled.

The team led by Cocquyt have been able to "see" one of Leeuwenhoek's lenses directly, and although this may seem a continuation of the ever-closer focus of analytic studies onto specific instruments and workshops, in fact the conclusion of their research leads in a quite different direction. Prior to the recent neutron tomography, the most thorough account of Leeuwenhoek's lens-making technique concluded that he had in fact utilised a "secret" technique in which a sphere of glass is blown and the bulging section that forms at the base of the sphere is then removed and used as a

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[62] As we have seen above, the latter end of this date range is given by the Adler team themselves. The much earlier date can be found in, for example, Pollard, Batt, Stern, & Young (2007, p. 18).

[63] Cocquyt, Zhou, Plomp, & Van Eijck (2021).

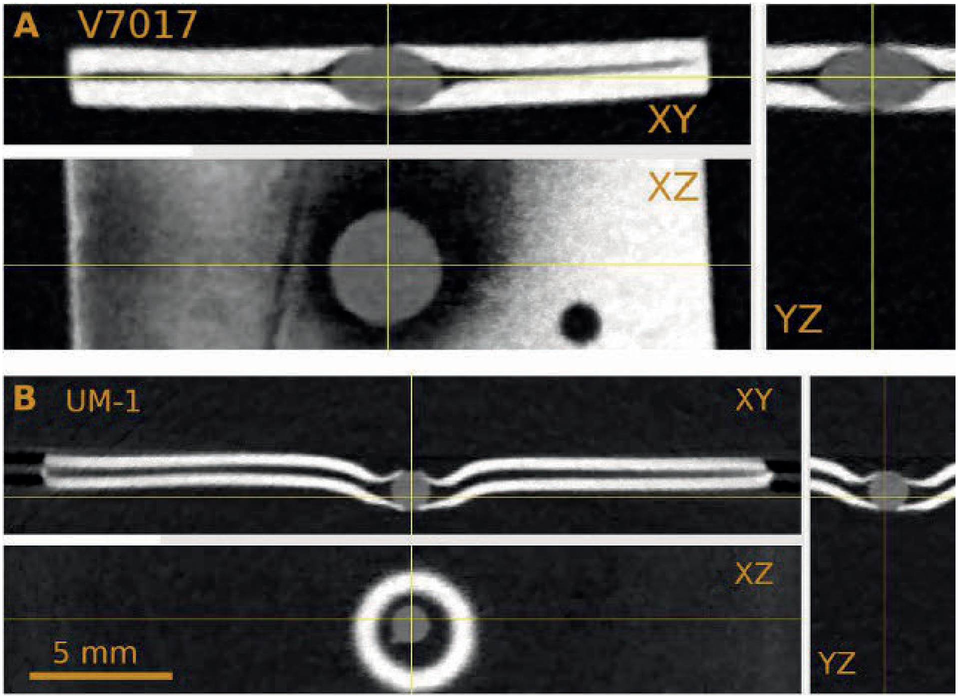

Figure 4. Orthogonal cross sections of computed tomography of the Van Leeuwenhoek microscopes from Leiden and Utrecht. The XZ projection of the circular cross section of the high-power microscope (UM-1) shows that this ball-shaped lens has a tiny glass stem connected to it. From "Neutron Tomography of Van Leeuwenhoek's Microscopes" by T. Cocquyt, Z. Zhou, J. Plomp, & L. Van Eijck (2021), *Science Advances*, 7, p. 3. Reproduced with permission.

lens.[64] This offered a good explanation for the special features of Leeuwenoek's lenses —unusually high resolution and magnification, and a smooth surface indicating that the lenses were not ground and then polished but were formed by heat alone—and also seemed to fit with the idea the Leeuwenhoek was simply an excessively talented craftsman who had discovered or perfected a technique specific to himself.

The glimpse of the lenses themselves offered by neutron tomography suggests quite a different explanation for Leeuwenhoek's success. As we saw earlier, most previous writers on Leeuwenhoek had assumed that his lenses were lentil-shaped, that is, bi-convex with a shallow curvature. This could fit with either grinding/polishing or the unusual technique involving a blown sphere mentioned above. Cocquyt et al. analysed two microscopes, finding that the lower-power of the two did indeed have a bi-convex shape, with extremely fine tapers, suggesting grinding and polishing rather than the blown-sphere technique. But for the higher-power of the two lenses, the images produced by neutron tomography showed a surprise: this lens is not only almost perfectly spherical, but also has a small glass thread or stem on one

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[64] van Zuylen (1981).

side (see Figure 4). The only explanation for these two facts is that this high-power microscope, capable of magnifying up to 266 times, was produced using quite a well-known technique in the 17th century. Here, the end of a thin glass thread is melted in a flame, forming a small glass sphere that can then be broken off and used directly as a lens, leaving a small stem at the point where the thread was broken.

What is remarkable about this finding is that this technique was already in print at the time Leeuwenhoek began his microscopical researchers. Robert Hooke describes a version of it in his famous *Micrographia* of 1665, and then gives a variant in his lectures published in 1678 that results in exactly the kind of lens observed by Cocquyt and his colleagues. Hooke's approach is itself an improvement on an older technique that made use of a needle to hold a small piece of glass that could then be melted into a sphere—and Leeuwenhoek is known to have disapproved of this method. So in the high-power microscope we can in fact see Leeuwenhoek borrowing Hooke's improved melting technique.

The timing is particularly instructive: Leeuwenhoek first corresponded with the Royal Society about microscopy in 1673 and he had clearly been experimenting with different lens-making techniques for some time. Hooke bemoaned Leeuwenhoek's secrecy in print and sought a number of times to find out how his lenses were made. In fact, Leeuwenhoek had, it seems, adapted his lens-making technique in light of Hooke's own 1678 publication. Far from maintaining secrecy for the sake of a new or adapted technique, Leeuwenhoek held back information on a technique that the Royal Society itself had put forward in print. The older image of Leeuwenhoek was based, at least in part, on what scholars had assumed must have been a particular craft genius. Instead, Cocquyt and his colleagues have used new analytic techniques to reveal that Leeuwenhoek, like all other craftspeople, was part of a network of innovation, improvement, and adaptation.

In this more sophisticated and transactional understanding of Leeuwenhoek's technique, we remain interested in the man and his technique, and also in the interaction between secrecy and openness—but the latter are not considered as a simple opposition, and the former can be understood in a social, practical, intellectual, and even economic context. Rather than looking in ever closer detail at the practices of a particular workshop, we can now think of a dynamic interplay between craft know-how, published or public expertise, people (labour), and materials. These components or aspects of technical knowledge must be set in motion: books, prints, and manuscripts obviously communicate over distance; people migrate, taking their skills and tools with them; apprentices move between workshops, sometimes even between guilds with different specialities; materials are traded, sometimes over large distances.

These arguments have been made more generally for knowledge production and circulation by Jim Secord, in his 2004 paper "Knowledge in Transit." There, Secord argues that scholars who had followed the turn to scientific practice—which "broke down old distinctions between words and things, between texts, books, instruments, and images"—had also and perhaps inadvertently tended towards an increasing specialisation that saw "the localizing of a piece of scientific work as a worthwhile end in itself." This tendency is clearly evident in the microhistories of particular workshops mentioned above. Against this, he urges that we as historians should "shift our focus and think about knowledge-making itself as a form of communicative action."[65] This straightforward sounding claim has profound consequences, especially for studies of material culture and the role of materials (and collections) in historical research. We have already given two examples of the ways in which aggregating technical analyses of instruments, with a special focus on craft and materiality, can shed light on matters of communication. In the case of early modern brass, the questions are straightforward: how widely (and how) did Eastern expertise spread? How and why did European metalworkers produce high-zinc brass in the years around 1600? These questions are fundamentally about communication, movement, and "transit." In the case of Leeuwenhoek, we would now like to know more about the development of his own technique, but no longer considered in isolation from other sources of information about lens manufacture. The revelation of the neutron tomography is that Leeuwenhoek's work must be understood in terms of the sharing of knowledge, even if this ultimately results in a spectacular instance of secrecy.

A final example clinches the point. Cocquyt has also been a collaborator on a project called "Dioptrice," which uses a range of techniques—laboratory-based, iconographic, textual, archival—to examine a large number of early telescopes.[66] The project is ambitious and a full summary is beyond the scope of this paper, but one finding stands out. Using a newly designed interferometer the team has examined the lenses of some of the earliest surviving telescopes, and has discovered that the crucial component of optical performance was the placing of an aperture that covered all but the "sweet spot" of the lens. This technique was not published in the period, and the finding confirms the speculation of Rolf Willach that the solution to the aperture problem in fact *constitutes* the "invention of the telescope."[67] Here, we have a dramatic example of the ways in which shared craft expertise circulated without any form of public presentation and perhaps even beyond the knowledge of most scholars and virtuosi. Like the revelation about Leeuwenhoek's lenses, which connects him to Hooke, this was more-or-less unknowable without the deployment of laboratory techniques—though in both cases the meaning of the findings demands a wide range of expertise about many aspects of intellectual, craft, economic, and social history.

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[65] Secord (2004, pp. 658, 659, 661).

[66] See Bolt & Korey (2019); Bolt, Cocquyt, & Korey (2018). This work builds upon a major research project begun in the early 1990s that was led by the Institute and Museum of the History of Science (now Museo Galileo) in Florence, which analysed glass-making techniques and the optical characteristics of early Italian telescopes. For a review of the project's findings, see Molesini (2010).

[67] See the papers, especially those by Willach and Bolt & Korey, in van Helden, Dupré, van Gent, & Zuidervaart (2010).

Conclusion

Our paper has traced the history of the "lab in the museum" from its origins in the narrow scientific calibration of Leeuwenhoek's microscopes through to the latest work analysing large collections of instruments in relation to the communities that made and used them. Temporality is an instructive framework through which to review this history. In the Leeuwenhoek work we found that the typical chronology of scientific measurement was reversed, with old calibrated against new. The result, we have argued, is a teleology, in which any given artefact can only be understood as a point on an arc of progress that is necessarily defined by the capacities of the instrument doing the calibrating. Historical time here is subordinated to a logic of progress, discovery, and "the technical frontier." Although dated in its approach and even its conclusions, there is still something instructive in the notion that materials themselves might determine our sense of historical duration. Turner's claim that discovery can be calibrated against optical performance has the rather surprising corollary that we might consider the history of science along multiple axes of time: the time taken for craft know-how to circulate; for materials to be unearthed, refined, moved, and worked; for information to circulate (or not); for instruments to circulate.

To this can be added the paradigm that we credit Derek Price with inaugurating, under which instruments are given historical meaning through the recovery of their relations with other instruments. So Price began with the narrow antiquarianism of the collector and fleshed out a chronology for the history of scientific instruments through the compilation of large datasets. One consequence was the unveiling of numerous anomalies—instruments that failed to fit this chronology and so were unmasked as fakes. Of course, only a limited subset of instruments ever made it into Price's chronology, but for those that did—astrolabes above all—the relations between instruments threw up a host of new research questions for which the lab in the museum proved particularly fruitful. What followed was a paradigm of analytical microhistory, in which the life history of individual instruments was revealed through exquisite attention to the materials and methods that went into their construction. This, of course, fed back into the larger chronology that Price had begun, expanding and fleshing out a material history of scientific practice.

There remains an obvious and longstanding problem with this kind of work. As brilliant and revelatory as much of it has been, by and large it remains liminal to the core disciplinary scholarship of history and philosophy of science (HPS). As Sam Alberti has noted, curators of science collections and academic historians of science have in many respects built two distinct disciplinary communities.[68] Our suggestion here is that a stronger bridge between these two strands of research is now beginning to form. This bridge has emerged, we suggest, from a new focus on collections of instruments as source materials for an understanding of two important facets of recent scholarship in HPS: craft communities and commodity exchange.

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[68] Alberti (2019).

From a curatorial perspective, this work might appear at first blush to emerge from little more than an amalgamation of Price's data-driven model and the microhistorical interests of modern instrument scholars. With attention to a large enough corpus of instruments, so this story goes, many microhistories might begin to network together into a study of craft communities. But we have shown in the final section of this paper that there is more than this going on. What the best recent studies of instruments *qua* communities demonstrate is the power of leveraging the close study of instruments—including the scientific analysis of them—within wider histories of knowledge. Such histories do not privilege instrumental knowledge nor do they delimit the contexts in which they are judged to work. Rather, they place them within a dynamic interplay of craft know-how, expertise, labour, commerce, and material exchange.

This, by necessity, is interdisciplinary work. It is therefore not a surprise to find that the examples we have drawn on in the latter parts of this paper tend to be collaborative projects that incorporate expertise from beyond the science museum. We can now conclude with a brief introduction to one more such project, recently begun by an interdisciplinary team that includes the authors of the present paper. The AHRC-funded project "Tools of Knowledge: Modelling the Creative Communities of the Scientific Instrument Trade, 1550–1914" brings together curators, historians, and experts in the field of Digital Humanities across five partner institutions.[69] Together, this interdisciplinary team will apply cutting-edge methods of digital analysis to data on almost four centuries of the scientific instrument trade in Britain. Building out from the SIMON database developed by Gloria Clifton and others since the 1980s, the project aims both to develop new digital tools for remodelling, interrogating, and making public this rich data, and to offer new historical insights from deeper case studies of particular facets of it.[70] By incorporating new methods from the "network turn" in Digital Humanities, and through the creation of additional collections-based datasets (including new data generated by XRF metallurgical analysis), the intention is to develop a new historical account of the production of scientific instruments over a more than 350-year period.[71] In this sense, "Tools of Knowledge" very much follows the lead of the kinds of projects described in our final section: it mobilises collections of objects and texts to think about materials, labour, and expertise in transit, over the *longue durée*. To be at all successful, such work will no doubt continue to rely upon the lab in the museum. But by moving beyond objects as localised datapoints, it will also re-centre instruments in wider accounts of past scientific practice—a move that promises to bring scientific collections into the very heart of the discipline of HPS.

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[69] For further information on the project and its outputs, see its website (https://toolsofknowledge.org/).

[70] Currently, the only publicly available data from the SIMON database appears in Clifton (1995). The "Tools of Knowledge" project will remodel the entire SIMON dataset using semantically modelled Linked Open Data, and make it publicly available online in a considerably enhanced and augmented form.

[71] On the "network turn" and Digital Humanities, see Ahnert, Ahnert, Coleman, & Weingart (2020). For a recent example using scientific collections, see Dutia & Stack (2021).

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References

Ahnert, R., Ahnert, S. E., Coleman, C. N., & Weingart, S. B. (2020). *The network turn: Changing perspectives in the humanities*. Cambridge, UK: Cambridge University Press.

Alberti, S. J. (2019). Scientific instrument curators in Britain: Building a discipline with material culture. *Journal of the History of Collections, 31*, 519–530. https://doi.org/10.1093/jhc/fhy027

Anderson, R. G. W. (1995). Connoisseurship, pedagogy or antiquarianism? What were instruments doing in the nineteenth-century national collections in Great Britain? *Journal of the History of Collections, 7*, 211–225. https://doi.org/10.1093/jhc/7.2.211

Antikythera Mechanism Research Project. (n.d.). Bibliography. *Antikythera Mechanism Research Project*. Retrieved from http://www.antikythera-mechanism.gr/bibliography

Baird, D. (2004). *Thing knowledge: A philosophy of scientific instruments*. Berkeley, CA: University of California Press.

Baker, H. (1739–1740). An account of Mr. Leeuwenhoek's microscopes. *Philosophical Transactions of the Royal Society of London, 41*, 503–519.

Bedini, S. A. (1965). The evolution of science museums. *Technology and Culture, 6*, 1–29.

Bennett, J. (2003). Knowing and doing in the sixteenth century: What were instruments for? *British Journal for the History of Science, 36*, 129–150. https://doi.org/10.1017/S000708740300503X

Bennett, J. (2009). Sundials and the rise and decline of cosmography in the long sixteenth century. *Bulletin of the Scientific Instrument Society, 101*, 4–9.

Berger, J. (2016). Walter Benjamin, antiquarian and revolutionary. In T. Overton (Ed.), *Landscapes: John Berger on art* (pp. 54–59). London, UK: Verso Books.

Bolt, M., Cocquyt, T., & Korey, M. (2018). Johannes Hudde and his flameworked microscope lenses. *Journal of Glass Studies, 60*, 207–222.

Bolt, M. P., & Korey, M. (2019). Dioptrice. *Journal of Glass Studies, 61*, 270–276.

Champion, M. S. (2017). *The fullness of time: Temporalities of the fifteenth-century Low Countries*. Chicago, IL: University of Chicago Press.

Chapman, A. (1983). A study of the accuracy of scale graduations on a group of European astrolabes. *Annals of Science, 40*, 473–488. https://doi.org/10.1080/00033798300200341

Clifton, G. (1995). *Directory of British scientific instrument makers 1550–1851*. London, UK: Zwemmer.

Cocquyt, T., Zhou, Z., Plomp, J., & Van Eijck, L. (2021). Neutron tomography of Van Leeuwenhoek's microscopes. *Science Advances, 7*, eabf2402. https://doi.org/10.1126/sciadv.abf2402

Collins, H., & Pinch, T. (1993). *The golem: What you should know about science*. Cambridge, UK: Cambridge University Press.

Connor, R. D., & Simpson, A. D. C. (2004). *Weights and measures in Scotland: A European perspective* (A. D. Morrison-Lowe, Ed.). Edinburgh, UK: National Museums Scotland.

Davis, J. (2017). A royal English medieval astrolabe made for use in northern Italy. *Journal for the History of Astronomy, 48*, 3–32. https://doi.org/10.1177/0021828616681214

Davis, J. (2019). The "Chaucerian" astrolabe in the British Museum: A reassessment of its dating and ownership. *Journal for the History of Astronomy, 50*, 121–154. https://doi.org/10.1177/0021828619845585

Davis, J., Degenaar, B., de Ruiter, A., van Gent, R., Pappot, A., & Agostino, A. (2020). A previously unrecorded medieval Latin astrolabe and evidence for a mid-fourteenth century instrument workshop. *Bulletin of the Scientific Instrument Society, 146*, 6–23.

Davis, J., & Lowne, M. (2015). An early English astrolabe at Gonville & Caius College, Cambridge, and Walter of Elveden's Kalendarium. *Journal for the History of Astronomy, 46*, 257–290. https://doi.org/10.1177/0021828615590336

Davis, J., & Schechner, S. (2018). The puzzle of a "reproduction" astrolabe in the style of Jean Fusoris. *Bulletin of the Scientific Instrument Society, 139*, 8–16.

De Clerq, P. (Ed.). (2000). *Scientific instruments: Originals and imitations; the Mensing connection*. Leiden, The Netherlands: Museum Boerhaave.

Desborough, J. (2019). *The changing face of early modern time, 1550–1770*. Cham, Switzerland: Palgrave Macmillan.

Dobbell, C. (1932). *Anthony Van Leeuwenhoek and his "little animals," being some account of the father of protozoology and bacteriology and his multifarious discoveries in these disciplines*. London, UK: Bale.

Dutia, K., & Stack, J. (2021). Heritage connector: A machine learning framework for building linked open data from museum collections. *Applied AI Letters, 2*, e23. https://doi.org/10.1002/ail2.23

Falk, S. (2014). The scholar as craftsman: Derek de Solla Price and the reconstruction of a medieval instrument. *Notes and Records: The Royal Society Journal of the History of Science, 68*, 111–134. https://doi.org/10.1098/rsnr.2013.0062

Findlen, P., & Toledano, A. (2018). The materials of natural history. In H. Curry, N. Jardine, J. Secord, & E. C. Spary, (Eds.), *Worlds of natural history* (pp. 151–169). Cambridge, UK: Cambridge University Press.

Folkes, M. (1722–1723). Some account of Mr. Leeuwenhoek's curious microscopes, lately presented to the Royal Society. *Philosophical Transactions of the Royal Society of London, 32*, 446–453.

Ford, B. J. (1981). The van Leeuwenhoek specimens. *Notes and Records of the Royal Society of London, 36*, 37–59. https://doi.org/10.1098/rsnr.1981.0003

Fors, H., Principe, L. M., & Sibum, H. O. (2016). From the library to the laboratory and back again: Experiment as a tool for historians of science. *Ambix, 63*, 85–97. https://doi.org/10.1080/00026980.2016.1213009

Fransen, S. (2019). Antoni van Leeuwenhoek, his images and draughtsmen. *Perspectives on Science, 27*, 485–544. https://doi.org/10.1162/posc_a_00314

Frasca-Spada, M., & Jardine, N. (Eds.). (2000). *Books and the sciences in history*. Cambridge, UK: Cambridge University Press.

Freeth, T. (2015). Reconstructing the Antikythera Mechanism. In C. Ruggles (Ed.), *Handbook of archaeoastronomy and ethnoastronomy* (pp. 1603–1624). New York, NY: Springer.

Ginzburg, C. (1993). Microhistory: Two or three things that I know about it (J. Tedeschi & A. C. Tedeschi, Trans.). *Critical Inquiry, 20*, 10–35. https://doi.org/10.1086/448699

Gooday, G. J. (2004). *The morals of measurement: Accuracy, irony, and trust in late Victorian electrical practice*. Cambridge, UK: Cambridge University Press.

Gordon, R. B. (1986). Metallography of brass in a 16th-century astrolabe. *Historical Metallurgy, 20*, 93–96.

Gordon, R. B. (1987). Sixteenth-century metalworking technology used in the manufacture of two German astrolabes. *Annals of Science, 44*, 71–84. https://doi.org/10.1080/00033798700200121

Gunther, R. T. (1932). *The astrolabes of the world* (2 Vols.). Oxford, UK: Oxford University Press.

Hacking, I. (1983). *Representing and intervening: Introductory topics in the philosophy of natural science*. Cambridge, UK: Cambridge University Press.

Hall, A. R. (2006). The first decade of the Whipple Museum. In L. Taub & F. Willmoth (Eds.), *The Whipple Museum of the History of Science: Instruments and interpretations, to celebrate the 60th anniversary of R. S. Whipple's gift to the University of Cambridge* (pp. 57–68). Cambridge, UK: Whipple Museum of the History of Science.

Heering, P., & Wittje, R. (Eds.). (2011). *Learning by doing: Experiments and instruments in the history of science teaching*. Stuttgart, Germany: Franz Steiner Verlag.

Higgitt, R. (2003). "Newton depossede!": The British response to the Pascal forgeries of 1867. *British Journal for the History of Science, 36*, 437–453. https://doi.org/10.1017/S0007087403005144

Higgitt, R. (2019). Instruments and relics: The history and use of the Royal Society's object collections c. 1850–1950. *Journal of the History of Collections, 31*, 469–485. https://doi.org/10.1093/jhc/fhy038

Hyslop, J. (2008). John Mayall and reproductions of early microscopes/two Leeuwenhoek-type microscopes. *Explore Whipple Collections*. Retrieved from https://www.whipplemuseum.cam.ac.uk/explore-whipple-collections/microscopes/dutch-pioneer-antoni-van-leeuwenhoek/mayall-reproductions

Jardine, B. (2019a). The museum in the lab: Historical practice in the experimental sciences at Cambridge, 1874–1936. *BJHS Themes, 4*, 245–271. https://doi.org/10.1017/bjt.2019.6

Jardine, B. (2019b). Like a Bos: The discovery of fake antique scientific instruments at the Whipple Museum. In J. Nall, L. Taub, & F. Willmoth (Eds.), *The Whipple Museum of the History of Science: Objects and investigations, to celebrate the 75th anniversary of R. S. Whipple's gift to the University of Cambridge* (pp. 201–221). Cambridge, UK: Cambridge University Press.

Johnston, S., Mörzer Bruyns, W. F. J., Deiman, J. C., & Hooijmaijers, H. (2003). The Anton Mensing scientific instrument project: Final report. *Bulletin of the Scientific Instrument Society, 79*, 28–32.

King, D. A., & Turner, G. L. (1994). The astrolabe presented by Regiomontanus to Cardinal Bessarion in 1462. *Nuncius, 9*, 165–206. https://doi.org/10.1163/182539184X00072

Kowal, E., Radin, J., & Reardon, J. (2013). Indigenous body parts, mutating temporalities, and the half-lives of postcolonial technoscience. *Social Studies of Science, 43*, 465–483. https://doi.org/10.1177/0306312713490843

Lamprey, J. P. (1997). An examination of two groups of Georg Hartmann sixteenth-century astrolabes and the tables used in their manufacture. *Annals of Science, 54*, 111–142. https://doi.org/10.1080/00033799700200491

List of synchrotron radiation facilities. (2021, August 8). *Wikipedia*. Retrieved from https://en.wikipedia.org/w/index.php?title=List_of_synchrotron_radiation_facilities&oldid=1037817014

Long, P. O. (1991). The openness of knowledge: An ideal and its context in 16th-century writings on mining and metallurgy. *Technology and Culture, 32*, 318–355.

Maas, A. (2013). How to put a black box in a showcase: History of science museums and recent heritage. *Studies in History and Philosophy of Science Part A, 44*, 660–668. https://doi.org/10.1016/j.shpsa.2013.07.013

Mayall, J. (1886). Leeuwenhoek's microscopes. *Journal of the Royal Microscopical Society, 6*, 1047–1049.

Mearns, D. L., Warnett, J. M., & Williams, M. A. (2019). An early Portuguese mariner's astrolabe from the Sodré wreck-site, Al Hallaniyah, Oman. *International Journal of Nautical Archaeology, 48*, 495–506. https://doi.org/10.1111/1095-9270.12353

Miller, P. N. (2017). *History and its objects: Antiquarianism and material culture since 1500*. Cornell, NY: Cornell University Press.

Miller, W. H. (1856). On the construction of the new imperial standard pound, and its copies of platinum; and on the comparison of the imperial standard pound with the kilogramme des archives. *Philosophical Transactions of the Royal Society of London, 146*, 753–946.

Molesini, G. (2010). Testing telescope optics of seventeenth-century Italy. In A. van Helden, S. Dupré, R. van Gent, & H. Zuidervaart (Eds.), *The origins of the telescope* (pp. 271–280). Amsterdam, The Netherlands: KNAW.

Momigliano, A. (1950). Ancient history and the antiquarian. *Journal of the Warburg and Courtauld Institutes, 13*, 285–315.

Mosley, A. (2007). Objects, texts and images in the history of science. *Studies in History and Philosophy of Science, 38*, 289–302. https://doi.org/10.1016/j.shpsa.2007.03.002

Newbury, B. D., Notis, M. R., Stephenson, B., Cargill, G. S., & Stephenson, G. B. (2006). The astrolabe craftsmen of Lahore and early brass metallurgy. *Annals of Science, 63*, 201–213. https://doi.org/10.1080/00033790600583162

Newbury, B. D., Stephenson, B., Almer, J., Notis, M. R., Cargill, G. S., Stephenson, G. B., & Haeffner, D. (2004). Synchrotron applications in archaeometallurgy: Analysis of high zinc brass astrolabes. *Powder Diffraction, 19*, 12–15. https://doi.org/10.1154/1.1649316

Notis, M., Newbury, B., Stephenson, B., & Stephenson, G. B. (2013). Synchrotron X-ray diffraction and fluorescence study of the astrolabe. *Applied Physics A, 111*, 129–134. https://doi.org/10.1007/s00339-012-7480-7487

Pollard, M., Batt, C., Stern, B., & Young, S. M. M. (2007). *Analytic chemistry in archaeology*. Cambridge, UK: Cambridge University Press.

Pollard, M., & Heron, C. (1996). *Archaeological chemistry.* Cambridge, UK: Royal Society of Chemistry.

Poole, K., & Williams, O. (Eds.). (2019). *Early modern histories of time: The periodizations of sixteenth- and seventeenth-century England*. Philadelphia, PA: University of Pennsylvania Press.

Price, D. J. (1956). International checklist of astrolabes. *Archives internationales d'histoire des Sciences, 32*, 243–263; *33*, 363–381.

Price, D. J. (1958). Fake antique scientific instruments. In *Actes du VIIIe Congrès international d'histoire des sciences: Florence–Milan 3–9 Septembre 1956* (pp. 380–394). Vinci, Italy: Gruppo Italiano di Storia delle Scienze.

Price, D. J. (1980). Philosophical mechanism and mechanical philosophy: Some notes toward a philosophy of scientific instruments. *Annali dell'Istituto e Museo di Storia della Scienza di Firenze, 5*, 75–85.

Rand, K. A. (2015). The authorship of the *Equatorie of the Planetis* revisited. *Studia Neophilologica, 87*, 15–35. https://doi.org/10.1080/00393274.2014.982355

Rehren, T., & Pernicka, E. (2008). Coins, artefacts and isotopes: Archaeometallurgy and *Archaeometry. Archaeometry, 50*, 232–248. https://doi.org/10.1111/j.1475-4754.2008.00389.x

Robertson, L. A. (2015). Van Leeuwenhoek microscopes: Where are they now? *FEMS Microbiology Letters, 362*, fnv056. https://doi.org/10.1093/femsle/fnv056

Rubio, F. D. (2020). *Still life ecologies of the modern imagination at the art museum*. Chicago, IL: University of Chicago Press.

Schaffer, S. (1997). Metrology, metrication, and Victorian values. In B. Lightman (Ed.), *Victorian science in context* (pp. 438–474). Chicago, IL: University of Chicago Press.

Secord, J. A. (2004). Knowledge in transit. *Isis, 95*, 654–672. https://doi.org/10.1086/430657

Stephenson, G. B., Stephenson, B., & Haeffner, D. R. (2001). Investigations of astrolabe metallurgy using synchrotron radiation. *MRS Bulletin, 26*, 19–23. https://doi.org/10.1557/mrs2001.14

Tal, E. (2017). Calibration: Modelling the measurement process. *Studies in History and Philosophy of Science Part A, 65*, 33–45. https://doi.org/10.1016/j.shpsa.2017.09.001

Taub, L. (2009). On scientific instruments. *Studies in History and Philosophy of Science, 40*, 337–343. https://doi.org/10.1016/j.shpsa.2009.10.002

Taub, L. (2011). Reengaging with instruments. *Isis, 102*, 689–696. https://doi.org/10.1086/663605

Turner, A. (1995). From mathematical practice to the history of science: The pattern of collecting scientific instruments. *Journal of the History of Collections, 7,* 135–150. https://doi.org/10.1093/jhc/7.2.135

Turner, A. (2003). John Dee, Louvain and the origins of English instrument making. In M. Beretta, P. Galluzzi, & C. Triarico (Eds.), *Musa musaei: Studies on scientific instruments and collections in honour of Mara Miniati* (pp. 63–78). Florence, Italy: L. S. Olschki.

Turner, G. L. (1967). The microscope as a technical frontier in science. In S. Bradbury & G. L Turner (Eds.), *Historical aspects of the microscope* (pp. 175–199). Cambridge, UK: Heffers.

Van Der Star, P. (1953). *Descriptive catalogue of the simple microscopes in the Rijksmuseum voor de Geschiedenis der Natuurwetenschappen at Leyden*. Leiden, The Netherlands: Rijksmuseum voor de Geschiedenis der Natuurwetenschappen.

Van Helden, A., Dupré, S., van Gent, R., & Zuidervaart, H. (Eds.). (2010). *The origins of the telescope*. Amsterdam, The Netherlands: KNAW.

Van Helden, A., & Hankins, T. L. (1994). Instruments in the history of science. *Osiris, 9,* 1–6. https://doi.org/10.1086/368726

Van Zuylen, J. (1981). The microscopes of Antoni van Leeuwenhoek. *Journal of Microscopy, 121,* 309–328. https://doi.org/10.1111/j.1365-2818.1981.tb01227.x

Zuidervaart, H. J., & Anderson, D. (2016). Antony van Leeuwenhoek's microscopes and other scientific instruments: New information from the Delft archives. *Annals of Science, 73,* 257–288. https://doi.org/10.1080/00033790.2015.1122837