The Invisible Technician

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Steven Shapin

London, 1675. Turn east at St. James's Palace onto the south side of Pall Mall. Pass the houses of fashionable physician Thomas Sydenham and royal mistress Nell Gwyn. At about the middle of the street, knock on the door of a three-story house owned by Katherine, Countess of Ranelagh, and seek admittance to the laboratory at the back presided over by her brother, the chemist and natural philosopher Robert Boyle.

Boyle's laboratory is a densely populated workplace, housing a variety of individuals laboring to produce scientific knowledge, each performing a relatively distinct role. In the corner, Boyle himself is dictating to one of his several amanuenses, for since his early years he has rarely put his own pen to paper. Indeed, the laboratory notes from which he is dictating were themselves produced by others' hands. Now and again, an assistant reads and summarizes scientific texts for Boyle to avoid strain on the master's eyes. On a busy day, several chemical assistants work in the laboratory, tending distillations, amalgamations, and rectifications, making observations and recording them for Boyle's use. Other assistants are carrying out experiments with the air pump or hydrostatic instruments. An apothecary who lives in Boyle's house prepares tinctures of herbal extracts for medicinal use. Technicians leave with Boyle's orders for observations and experiments to be made elsewhere and arrive with notes of their results. From time to time, the laboratory is visited by instrument makers bearing improved or repaired devices for physical experimentation and observation: pumps, baroscopes, thermometers, microscopes, and telescopes. Boyle's colleague and former retainer Robert Hooke drops in several times a week, bringing with him mechanical contrivances, chemicals, and scientific publications and occasionally working in the laboratory for extended periods. (Two years later, in his capacity as architect, Hooke will design an entirely new laboratory for Boyle.) A female servant tells Boyle about a luminescent piece of meat she has discovered in the larder. Domestic servants rush in and out with porringers of blood from the butcher's for Boyle's examination, fruit, fish, and flies to be placed in the receiver of the air pump, and post for the amanuenses to read to Boyle.

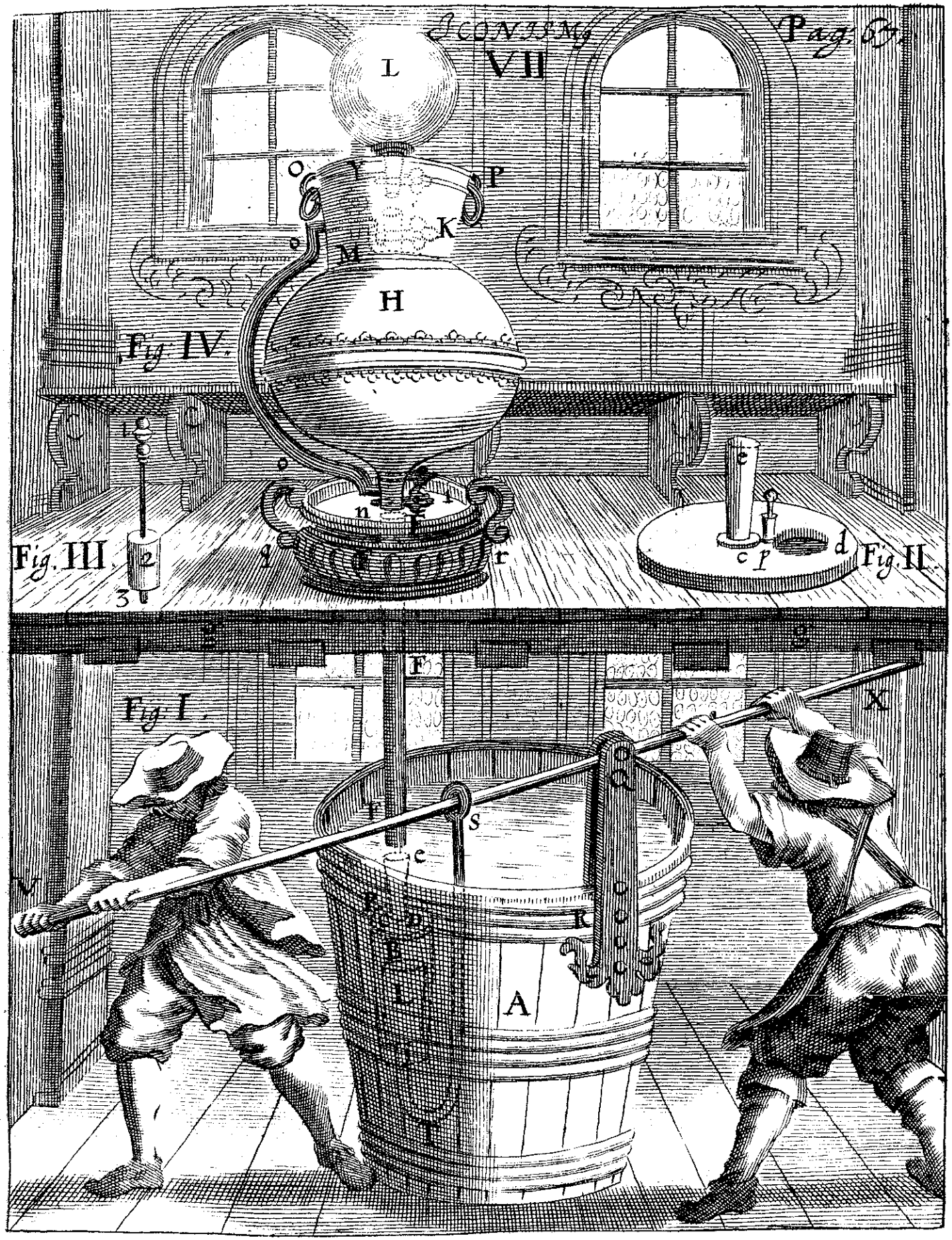
Domestic touches aside, a modern scientist might recognize this sort of place. Indeed, in seventeenth-century terms Boyle's laboratory counted as Big Science. Apart from astronomical observatories, few early modern sites associated with the production of scientific knowledge were marked by such a differentiation of labor or were so densely inhabited (Hall 1987; Shapin 1988).

The transparency of technicians' roles in making scientific knowledge reflects both historical and modern attitudes toward the value of skilled work

Boyle's support personnel went under a variety of designations. "Amanuenses" were customarily accorded their traditional clerical title, although they might occasionally perform technical functions as well; chemical assistants were commonly referred to as "laborants"; those engaged to tend and maintain mechanical contrivances were "operators," and the builders of such instruments were "artificers"; and all of these might also be designated by the generic title "assistants." Commonly, however, a blanket term was used to refer to the support personnel so employed: "servants" or, at times specifically, "chemical servants." The term "technician" referring particularly to someone working in a natural scientific context was not a seventeenth-century usage; like the word "scientist," it did not come into general use until this century.

Who were these assistants, and what did they do? So far as we know, all of Boyle's operators and laborants were male. Like household servants in general, they were probably engaged for a stated period, typically a year at a time, to reside within the household and to supply their labor at their master's command. (Boyle's technicians, unlike, for instance, Hooke's, were not apprentices being trained to acquire their master's abilities.) In the laboratory context, technicians' labor was usually

Figure 1. Historians of science have shown little inclination to study the roles of technicians or other support personnel involved in making and recording scientific knowledge. The problem of reconstructing technicians' work is partly a practical one: the historical record contains little evidence concerning support personnel, and what evidence there is requires careful interpretation. Note the double invisibility of the assistants operating an early version of the air pump in the Magdeburg house of Otto von Guericke in the early 1660s. The picture represents them as faceless and hence lacking personal identity. Moreover, observers entering Guericke's house were not intended to see the basement mechanisms—human and artificial—by which the pump worked; they were intended only to marvel at the miraculous effects. (From Caspar Schott, *Technica curiosa* [Würzburg, 1664].)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deemed to involve physical effort or manual skill, but, with few exceptions, little knowledgeability. While clerical servitude might be a transitional stage for young graduates on their way to careers in the church or law, technical servitude appears to have been a relatively stable state: one chemical servant resided with Boyle and worked for him for many years and may originally have been a family retainer. Thus the seventeenth-century technician can be defined by his remuneratively engaged status, his dependence upon the commands of his master, and the ascription to him of, at most, skill rather than knowledgeability about the operations he was paid to carry out (Maddison 1955).

All these laborants, operators, artificers, and servants did different things in making Boyle's science. Yet they had one characteristic very much in common: they were largely invisible. Indeed, they are doubly invisible. They were arguably invisible to Boyle and those for whom he wrote in the seventeenth century: in the whole of Boyle's published work and correspondence, there are no more than a handful of named references to them and their roles. And technicians have been almost wholly invisible to the historians and sociologists who study science: in the now-vast academic literature in the history and sociology of science there still does not exist a single study systematically documenting and interpreting technicians' work, past or present. (Chandra Mukerji's forthcoming study of American oceanography will have several chapters devoted to technicians' roles, and a large-scale study of the Hall Institute in Melbourne by T. D. Stokes of the University of Wollongong and others will also address the work of support personnel.) So far as one can tell from typical studies of the scientific revolution, there was no one in Boyle's laboratory but Boyle himself, no persons involved in the production of science but the stipulated authors of texts.

The historical problem is therefore twofold: one wants to document and to clarify the significance of technicians' work, yet one also wants to explain why it was that they were largely transparent to the gaze of those who employed them—how and why, that is, such a fundamental distinction was made between the value of what they did and what their masters did, between their invisibility and their employers' authority.

Who did Boyle's experiments?

The retrieval of technicians' work immediately confronts a body of rhetoric associated with the new science of seventeenth-century England. Unlike the "barren" scholasticism of the universities, unlike the "metaphysical" discourses of modern rationalists, the new experimental science was said to be a hands-on practice. Francis Bacon in the early seventeenth century and the leaders of the new Royal Society of London in the 1660s repeatedly stressed the importance of a program of real, "artificial" experimentation in the making of a genuine, objective, and useful natural science. Experiments had really, and laboriously, to be done, not merely to be "thought." Authentic science depended upon actual experiments, performed, witnessed, and attested by the practitioners themselves. One of the Royal Society's most influential publicists, Thomas Sprat, described it as the "Fundamental Law" of the Society "that whenever they could possibly get to handle the subject, the Experiment was still perform'd by some of the Members themselves" (Sprat 1667, p. 83). Rejecting traditional contempt for manual operations, the new gentleman-philosopher was not to think of himself as demeaned by mucking about with chemicals, furnaces, and pumps; rather, his willingness to make himself, as Boyle said, a mere "drudge" and "under-builder" in the search for God's truth in nature was a sign of his nobility and Christian piety (Boyle 1772, vol. 1, pp. 300–07).

Figure 2. Another artistic convention that worked to ensure technicians' invisibility in the seventeenth century was the depiction of agents operating scientific instruments as putti, or cherubs, rather than human beings. This example shows putti operating Guericke's first air pump. (From Caspar Schott, *Mechanica hydraulico-pneumatica* [Würzburg, 1657].)

The rhetoric that presented new scientists like Boyle as craftsmenlike practical doers has been immensely effective, as witnessed, for instance, by a modern historian's assurance that "no one could doubt that [Boyle] performed all the experiments he reported, hundreds and hundreds, thousands of them" (Gillispie 1960,

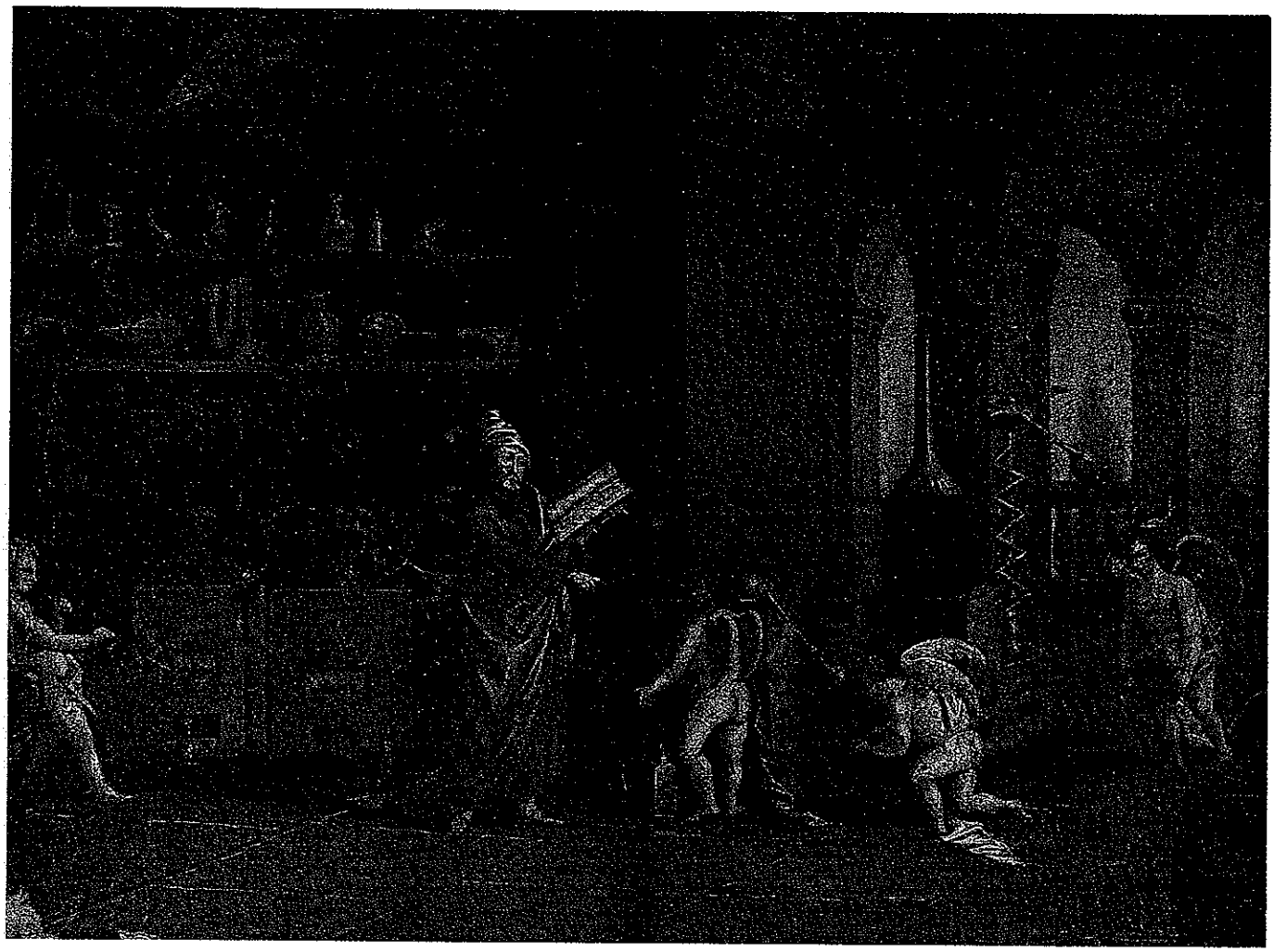

Figure 3. The new experimental science was often contrasted to the older tradition of alchemy. But this anonymous seventeenth-century painting of an alchemical laboratory also portrays assistants as putti. (Copyright Museum of the History of Science, University of Oxford.)

p. 103). Yet the sense in which Boyle and other seventeenth-century gentlemen–experimental philosophers performed those experiments needs to be very carefully qualified. Thus, while Boyle endorsed the sentiment that it was only a matter of "effeminate squeamishness" for a gentleman to disdain performing the operative part of scientific work, he offered his own thankful testimony that he was routinely able to make "experiments by others' hands" (Boyle 1772, vol. 2, p. 14). Indeed, despite the rhetoric, it is more than likely that very few—rather than "all"—of Boyle's experiments involved the laying of his hands upon experimental apparatus or materials. A very substantial proportion of Boyle's experimental work was done on his behalf by paid assistants. There is little reason to think that Boyle was much different from his scientific contemporaries in this respect.

What was the nature and scope of technicians' work in Boyle's laboratory? At one extreme, technicians might be seen as mere sources of physical energy and as muscular extensions of their master's will, shifting about heavy instruments and materials, hewing wood for the furnaces, drawing water for chemical operations. This is the sort of work that both seventeenth-century and present-day scientists tend to regard as of no importance to the production of knowledge. Though science could not be made if this work were not done, it is thought that anyone can do it, that such workers are easily interchangeable on the labor market, and that no knowledgeability and little skill are involved in its performance. Remunerated assistants also functioned as operators of Boyle's instruments and conductors of his chemical experiments. For instance, Boyle's texts repeatedly, if obliquely, refer to the "lusty and dexterous" assistants who performed the often arduous work of drawing down the piston (or "sucker") of the air pump in order to produce an operational vacuum: "he who manageth the pump," "he that draweth down the sucker," "the pumper," and so forth (Shapin and Schaffer 1985, pp. 25–79). In such cases, there is intermittent recognition that some degree of skill might be involved in the work and that hands-on experience might accord a kind of craft or tacit knowledge. Indeed, there is evidence that

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Figure 4. This 1664 engraving of Robert Boyle is a study in scientific proprietorship. In the background is the air pump that was widely referred to eponymously as the *machina Boyleana*. In fact, it was probably constructed for Boyle by Robert Hooke, and the maintenance and operation of the pump were largely the concern of a number of assistants and instrument makers, few of whose names we now know. In general, we possess few visual representations of the practice of making scientific knowledge, as opposed to images of scientific authors and of the hardware used. There are no pictures of Boyle's laboratories or of any other seventeenth-century English laboratory. (Ashmolean Museum, Oxford.)

Boyle at least occasionally questioned technicians' judgments informed by their tacit knowledge. He once recorded his operator's opinion that it would not be worthwhile to continue exhausting the air pump to achieve a certain effect. Yet the point of the anecdote was that the technician's judgment was wrong. Boyle ordered his man to persevere, with results that, in Boyle's view, proved the superiority of philosophical knowledgeability over mere skill (Boyle 1772, vol. 3, p. 576).

Boyle relied not only on his technicians' hands but also on their eyes and judgment. According to his own published testimony, much of the labor of observing and recording experimental outcomes was given over to paid assistants. The extent of Boyle's reliance upon his technicians' eyes derives partly from his particular circumstances: he said that his own eyesight was poor and that his fragile health precluded him, for example, from carrying a barometer up a hill and recording the mercury level directly (Boyle 1772, vol. 3, p. 224). More generally, Boyle was frequently absent from his laboratory on other business for extended periods, during which he devolved the whole responsibility for managing and recording experiments to his assistants. To be sure, the printed texts rarely specify who, other than the authorial first person, made a given observation. When the outcome accorded with expectation, no observing agent was customarily specified; it was simply treated as the "visible testimony of nature."

Technicians' roles as observers and recorders were alluded to mainly when inconsistent or problematic results were obtained. Thus, a number of Boyle's experiments in the 1670s on flame, combustion, and phosphorescence involved delicate visual judgments, in which the onset of the phenomena to be witnessed was troublesome to establish and about which different observers routinely disagreed (Golinski 1989). Boyle recognized that this inescapable reliance upon his assistants' competence and sincerity as observers precipitated a critical problem of social relations at the core of the processes for making scientific knowledge, the problem of trust. Unless the master-scientist was to make all experiments by his own hands and all observations by his own eyes, he had to decide whom he might trust and in what circumstances. In fact, trust in his technicians posed itself as a substantial practical problem almost solely in cases where findings were ambiguous or anomalous from Boyle's theoretical point of view. The combustion experiments recurrently produced such reported outcomes, and in this context Boyle noted that the observational testimony of two assistants was insufficient for establishing the experimental matter of fact. He would cause the experiment in question to be repeated "for my fuller satisfaction," thus freeing himself, as he said, "from the need of trusting others' eyes" (Boyle 1772, vol. 3, p. 572).

Boyle offered his own thankful testimony that he was routinely able to make "experiments by others' hands"

The visible technician

Technicians' work was transparent when the apparatus was working as it should and the results were as they ought to be. In contrast, the role of technicians was continually pointed to when matters did not proceed as expected. In such circumstances, technicians' labor (or, rather, the incompetence of their labor) became highly visible. Their doings then became an important source of opaqueness between the master's eye and natural reality. Importantly, technicians' capacity to subvert—that is, to make mistakes and trouble—came to constitute an understood moral resource for explaining and excusing experimental failure.

In fact, situations in which experiments miscarried provide by far the richest source in Boyle's texts for establishing the nature and scope of his assistants' laboratory work. Artificers delivered defective instruments and impure or adulterated experimental materials; laborants misinterpreted or ignored directions that Boyle regarded as clear and unambiguous; a pneumatic trial

was ruined "in our absence . . . by the negligence or mistake of those we appointed to attend it." Boyle and an Oxford colleague were sitting placidly by the fire when they were "surprized by a sudden noise" in the adjoining room. It was the air pump blowing up, caused by a feckless young assistant working the pump too "obstinately."

Boyle reported a large number of experimental catastrophes in some detail, most caused by the failings of his assistants and most, fortunately, taking place while he was out of harm's way. Probably the most dangerous experimental trials Boyle ever conducted concerned the conditions for and nature of explosions. Early in the series he had become aware of the potential hazards involved in mixing nitric acid and alcohol. In one instance the operation caused so violent an explosion that some of the liquid "flew out of the glass, and hit against the ceiling of the room," then dripping down fell "upon his face that held the glass [and] made him think (as he told me) that fire had fallen upon it, and made him run down the stairs like a madman, to quench the heat at the [water] pump." Boyle's response was to bid "the laborant proceed more warily" (Boyle 1772, vol. 3, p. 593).

Now fully cognizant of the risks of these experiments, Boyle gave his assistant even more detailed instructions and directed that the trials be made in a room big enough so that any spectators would not be in danger "and that even the operator, that shook the vessel, should stand at a convenient distance from the mixture." Unfortunately, if predictably, the technician did not do as he was told, and, as Boyle related,

> Whilst I was withdrawn to a neighbouring place to write a letter, the operator . . . rashly inverted the instrument, without taking care to get away; when it happened, that as soon as ever the contained liquor . . . [was] poured out . . . there was so surprizing and vehement an expansion or explosion made, that with a great noise (which as the laborant affirmed, much exceeded the report of a pistol) the glasses were broken into a multitude of pieces, many of which I saw presently after, and a pretty deal of the mixture was thrown up with violence against the operator's doublet and his hat, which it struck off, and his face; especially about his eyes, where immediately were produced extremely painful tumors, which might also have been very dangerous, had I not come timely in, and . . . made him forthwith dissolve some saccharum Saturni in fair water, and with a soft spunge keep it constantly moistened by very frequent renewed applications of the liquor (Boyle 1772, vol. 3, pp. 594–95).

Shortly after this incident took place one of Boyle's assistants—presumably now horribly disfigured—was seeking safer employment with Isaac Newton in Cambridge (Newton 1959, p. 243).

Technicians and authors

To be sure, much of the work done by Boyle's remunerated assistants might be regarded as unskilled or semiskilled, posing no very obvious problems of interpreting the relationship between scientist and workman. But at the other extreme, consider this evidence of technicians' work from Boyle's preface to a report of air pump experiments published in 1680. Here, most unusually, Boyle gives the name of his paid assistant, Denis Papin, who is familiar to historians from his invention of an early pressure cooker, "Papin's digester" (Robinson 1947).

Figure 5. One of the few seventeenth-century technicians known to us by name is Denis Papin (1647–1712?), a Frenchman who served Boyle as experimental assistant for several years in the 1670s. Papin started his scientific career as a technician employed by Christiaan Huygens in Holland; it was Huygens who recommended him as an assistant to the experimental circle around the English Royal Society. After leaving Boyle's service, Papin worked as a technician at various times for the Royal Society and for a scientific academy in Venice. He was an underpaid professor of mathematics at Marburg before returning to England, where he died in obscurity and poverty. This lithograph, adapted from a portrait at the University of Marburg, shows Papin holding a diagram of his "digester," an early pressure cooker. (Wellcome Institute Library, London.)

According to Boyle's own testimony, this is what Papin did: he designed and constructed the particular instrument used in these experiments; he operated the instrument, either by himself or with the assistance of other technicians; he measured and recorded almost all of the experimental phenomena; and he planned and organized a great part of the experiments to be performed. Moreover, he composed at least a significant part, and possibly almost all, of the experimental reports. Boyle said that his technician was "desired to set down in writing all the experiments . . . as if they had been made and observed by his own skill." "I was not," Boyle acknowledged, "very sollicitous about the style, because, being infirm in point of health, and besides, surrounded with many businesses, I was enforced to leave the choice of words to monsieur *Papin*." Finally, Boyle said that he left at least some, and again probably most, of the interpretive work to his assistant: "Some few of these inferences owe themselves more to my assistant than to me" (Boyle 1772, vol. 4, pp. 505–07).

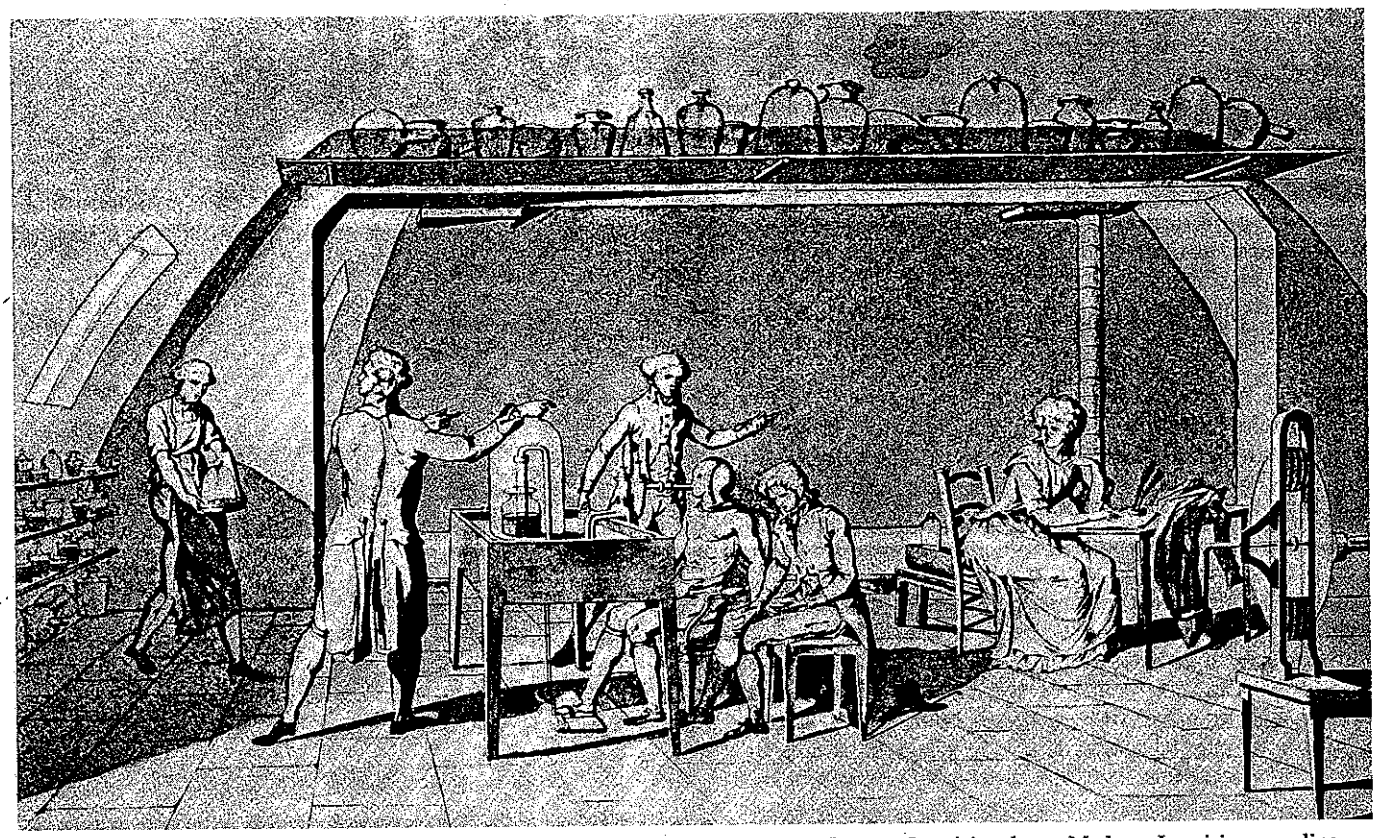

Figure 6. This scene from the late-eighteenth-century chemical laboratory of Antoine Laurent Lavoisier shows Madame Lavoisier recording experimental results at the right and a technician at the left carrying an instrument. Interestingly, a recent collection of scholarly essays about experimental practice that uses this picture on its cover retains Madame Lavoisier but crops the technician. (From E. Grimaux, *Lavoisier* [Paris, 1888].)

What, then, did Boyle do? Having engaged Papin and assured himself of Papin's general competence and reliability, he *trusted* the technician. He said that he was present at the "chief experiments"; that he asked Papin to keep him informed of what transpired during his absence; that he read over (or, more accurately, had read to him by an amanuensis) Papin's experimental narratives "that so no mistake might pass by unobserved about the experiments themselves." Boyle had no need to do more than that, for "I had cause enough to trust his skill and diligence" (Boyle 1772, vol. 4, p. 507).

Some modern sensibilities would have it that there was something wrong—something morally wrong—here. Having done all that he did, it might be thought that Papin should have been an author—perhaps the sole author. But he was not. At most it could be said that he did Boyle's experiments and wrote Boyle's text. Nor is there a shred of evidence available to the historian that would establish that Boyle thought what he did was wrong; that Papin, or, for that matter, Robert Hooke, who possibly did as much for Boyle, thought they were unfairly treated (Shapin 1989). In what contemporary sense, therefore, was Boyle, rather than Papin, the rightful author of this text?

The answer has an apparently tautological character. Boyle was the *author* because Boyle possessed *authority*. It was he who presided over the scientific workplace—indeed, it was his house; it was he who possessed the acknowledged right to set the agenda of work, who could effectively command the skilled labor of others, who could define the boundaries between skill and knowledge. It was he who was responsible for the work and who could say yes or no to its content and to the form of its appearance, whether or not he exercised that right. Finally, he enjoyed authority over those whose labor he engaged. It was for Boyle to hire and to fire, to place or to withhold trust in his servants' work. These are the senses in which the work done in Boyle's premises was considered to be legitimately his. In this connection, it made no difference that Papin was a medical graduate and already an author of a scientific text when he came to work for Boyle, or that he was widely considered to be not just a skillful but a knowledgeable agent. Papin's knowledgeability may have been the reason that Boyle's text gave him an identity, but in Boyle's house and service he functioned as Boyle's man. It was for Boyle to trust Papin or not. In Boyle's manuscript papers at the Royal Society there is a remarkable document, a draft oath to be signed by his technicians, engaging them to "be true to y^{e} trust repos'd by my . . . master in me" and committing them "in y^{e} faith of a Christian" to keep Boyle's scientific secrets (Boyle Papers, vol. 189, fol. 13r). Boyle himself, as is well known, declined the presidency of the Royal Society because he did not wish to take an oath.

Historical sensibilities

For all that, the modern sense that there might be something of moral significance going on here can be a useful one. Indeed, if seventeenth-century and present-day notions about work and authority differ, then they

may be said to proceed from different moral or political sensibilities. What, then, was the moral economy in terms of which seventeenth-century technicians were invisible?

At a basic level, the individualistic bias of much of Western culture has historically expressed itself in views of how proper knowledge is made. In science, as in art and literature, the prevalent model places a solitary individual in contact with reality or with sources of inspiration (Becker 1982). If we think of solitude as the proper situation for securing genuine insight, then we will regard a collective enterprise as doomed to yield at best mediocre or conventional knowledge. Moreover, a revelatory understanding of scientific discovery tends to stress momentary flashes of individual insight as opposed to extended trains of collective work. In fact, there is much anecdotal evidence that such individualistic and revelatory models of scientific activity persist—even in the modern age of Big Science—constituting a general cultural basis for the invisibility of technicians and other support personnel, and for our tendency to see science predominantly as thought rather than as work.

Secondly, one has to recognize that, despite the clamor of seventeenth-century English scientific rhetoric commending a hands-on approach, natural philosophy was still overwhelmingly a gentlemanly activity, and the traditional contempt that genteel and polite society maintained for manual labor was pervasive and deeply rooted. Other English natural philosophers than Boyle, like Thomas Hobbes, ridiculed practitioners who attempted to found science upon the manipulation of instruments as opposed to the exercise of rational thought, comparing the experimentalists of the Royal Society to "quacks," "mechanics," and "workmen" (Shapin and Schaffer 1985, pp. 125–39). The evaluative contrast between mere skill (or hand knowledge) and truly reflective and rational philosophical knowledgeability was basic. Indeed, the order of early modern society as a whole was arrayed about the distinction between those who worked and those who thought or fought. The seventeenth-century activity called natural philosophy participated in that distinction and displayed its consequences in the relations between philosophers and technicians.

Finally, the general relationship between master and servant was a basis for the latter's invisibility and lack of identity. All of Boyle's technicians—Papin as well as his anonymous predecessors and colleagues—were, in a strict and important sense, servants. They were all remuneratively engaged to do work at Boyle's behest. That is, they agreed to exchange a certain amount of autonomy and work for a certain amount of money. This circumstance seems banal in the modern scheme of things. The professionalization of science since the nineteenth century has meant that scientists are no longer gentlemanly amateurs but wage- and salary-laborers. Practically all present-day scientists and technicians exchange their labor for money and give up some of their freedom in doing so, nor is this situation thought to compromise the integrity of science. But to seventeenth-century sensibilities the wage relationship was charged with a particular political and moral significance.

During and after the English civil wars, there were wide-ranging debates over who should and who was able to participate in the political life of the nation. Disagreement was rife, yet many political thinkers, both parliamentary and royalist, agreed that all "servants"—which in contemporary usage was taken to mean all those who worked for others, who exchanged their labor for remuneration—should be excluded from the franchise. The reasoning behind this position was simple and clear: so long as an individual was a servant, he had "lost his birthright" as a freeborn Englishman. Inasmuch as he depended on the will of his master, the servant was considered to be unfree. His master spoke for him, and his voice was therefore "included in" that of his master. In this scheme of things, servants—male and female—were in precisely the same position as married and dependent women who were similarly invisible as political actors: wives were conceived to be "included in" their husbands, who spoke for them (Macpherson 1964; Kussmaul 1981).

It is not, in fact, a long way from debates over politics to the problem of technicians' invisibility. Technicians were servants; they were invisible in the political

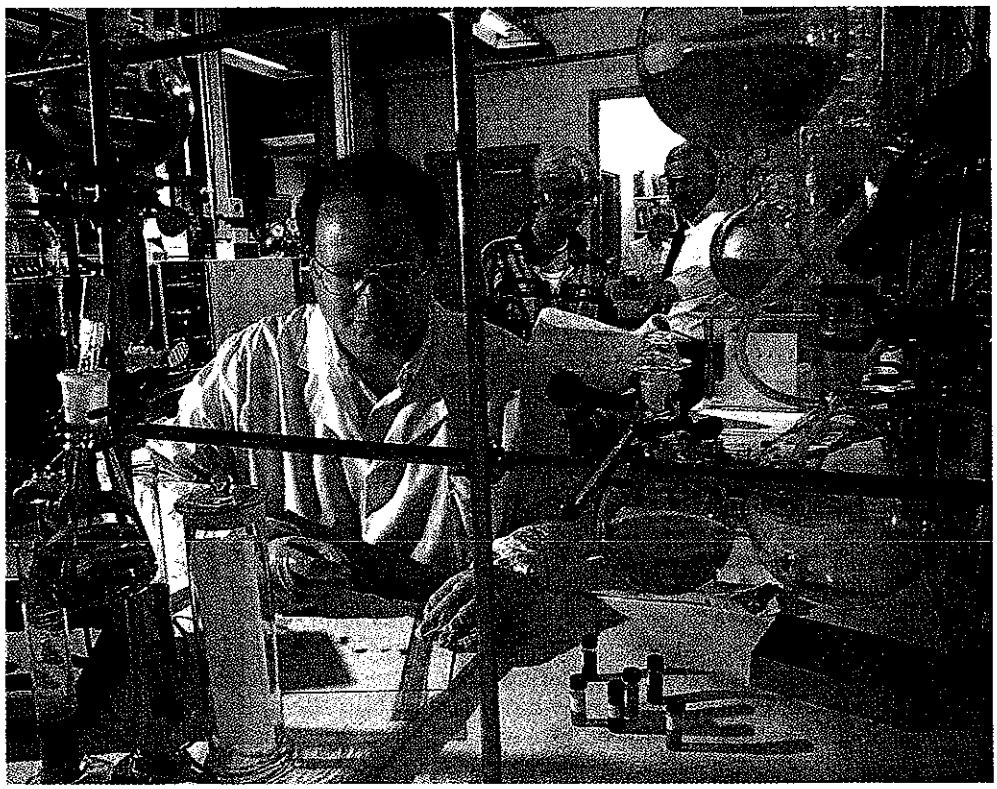

Figure 7. A scene from a day in the life of a modern American laboratory: Who is a scientist? Who is a technician? Identifying masters and assistants depends on our ability to interpret a series of codes common to scientific and lay culture—codes concerning dress, gesture, posture, expression, gender, and the like. (Courtesy of Research Triangle Institute.)

economy of science for the same reasons that underlay servants' general political exclusion. Papin was "included in" Boyle, and in that scheme of things Boyle spoke legitimately for him. Servitude compromised technicians' political integrity in the community of science and affected their credibility. Who could rely upon the testimony of people who were constrained? Servants might make machines work, but they might not make knowledge.

Modern sensibilities

It is tempting to make a clear distinction between seventeenth-century arrangements and the life of the modern laboratory. Thus, there would be almost universal rejection of language that described the relationship between present-day scientists and technicians in terms of masters and servants. As sociologists might say, modern science assigns individuals to their respective categories on the basis of "achieved" attributes (qualifications, assessments of relative knowledgeability) rather than on the basis of "ascribed" characteristics (gentility, "virtue"). Arrangements like these reflect the bureaucratization of science and its differentiation from the wider society, even though it was not many decades ago that the distinction between scientist and remunerated assistant could indeed be mapped onto that between gentleman and worker.

Given our systematic ignorance about the scientist-technician relationship in modern science, it would be foolish to venture more than speculations and impressionistic remarks. Nevertheless, one suspects that the historical arrangements and sensibilities described here are not wholly irrelevant to understanding the modern situation. At the most fundamental level, one should recognize that late-twentieth-century relationships, like their historical counterparts, manifest practical solutions to moral and political problems. Organizing the life of a laboratory, apportioning responsibility and credit, establishing the basis and scope of authority, and, often contentiously, deciding who should and should not appear as an author—all of these are routinely, and rightly, spoken of by scientists and technicians as moral questions. At the same time, practical answers to such questions manifest views about how science works and about what work is important in the making of scientific knowledge. In fact, settling the moral economy of the laboratory, including the scientist-technician relationship, is a constitutive part of the routine practices by which science is produced.

Of course, the ways in which modern scientific laboratories have solved, or attempted to solve, this moral problem vary enormously. Theoretical and experimental sciences have evolved different versions of the scientist-technician relationship, as have laboratories of different sizes. Laboratories in different organizational structures, with different trade union representations, and in different countries may have varying bureaucratic patterns imposed upon them, stipulating, for example, who may be a technician and who a scientist, how the transition between the two categories may be managed, and how scientists' authority may be brought to bear upon technicians' work. Nevertheless, in most cases there seems to be a significant amount of latitude in the management of these relationships, and individual laboratories—whatever their discipline or setting—manifest a range of moral economies.

Some laboratories are clearly organized on the principle of a rigid distinction between knowledgeable and skilled agents. In such places scientists think, while technicians carry out the manipulations dictated by the results of scientists' thoughts. Manipulative skill and hands-on experience are evidently not highly valued in such settings. Science here is seen largely as a reflective and rational activity. By contrast, there are many laboratories in which the distinction between skilled and knowledgeable people, and correspondingly between technicians and scientists, is blurred. It is believed in laboratories of this sort that genuine understanding is properly based upon the direct experience that can come only from working with the materials or processes under study. Here there may be talk of the value of "good hands" or of the importance of a "feeling for" organisms, data, or apparatus.

Yet within this variation in the moral economy of the laboratory, there appear to be certain fundamental elements in the scientist-technician relationship. And these invariants seem to link present-day arrangements with the historical past. Both the modern and the seventeenth-century technician—insofar as one can distinguish a discrete role—are evidently defined by their dependence and by an evaluative distinction between skill and knowledgeability. If the distinct roles of scientist and technician exist, it is the scientist who possesses the acknowledged authority and the scientist who is in a position to define the nature, scope, and meaning of technicians' labor. In modern settings we would customarily say that this authority is legitimated by credentials which objectively signify differential acquisition of relevant knowledge. Indeed, in one recent exchange concerning technicians' roles a scientist bridled at the very idea of Ph.D. technicians. According to this scientist, "It is not easy to complete a Ph.D. thesis. It requires qualities that are not compatible with those needed in a good technician. Scientists employ technicians to carry out the routine aspects of research, thus freeing their own time for more interesting and intellectually demanding problems" (Roberts 1983). Not surprisingly, the critical response from a technician, entitled "Technicians Are Scientists, Too," argued that the career structures of both scientists and technicians in universities should be merged into one new encompassing group called "scientific officers" (Hooper 1983).

Scientists' authority over technicians typically means that it is the former who decide how officially to arrange the relationship, whether to "make them" authors or coauthors, what counts as genuine knowledge as opposed to mere skill, and what technicians' work signifies in scientific terms. Yet just because these arrangements are moral and political in character, it is possible that there will be differences in view about whether such solutions are fair and legitimate or not. And in fact anyone who has worked in a scientific laboratory, however briefly, may be aware of such divergences of opinion. While many laboratories doubtless manifest consensus about how they are run, some clearly do not. In such cases, for example, technicians may say—albeit under their breaths—that scientists have

"taken credit" for work which is not "theirs," that it is technicians that are the "really important" or "indispensable" agents, or that the officially knowledgeable agents in fact "do not know what is going on." Thus, the very criteria of authority, dependence, and knowledgeability used to distinguish scientist and technician are contestable in principle. Almost needless to say, it is not the historian's or sociologist's job to take sides in such conflicts. But they are vitally important matters in laboratory life, and precisely because a nonscientist is not an interested party, his promptings to reflect on them may be useful.

Finally, there are reasons why historians and sociologists who wish to study and understand the nature of scientific activity should not allow technicians' work to be invisible. The predominant biases in the Western academic world have traditionally portrayed science as a formal and wholly rational enterprise carried out by reflective individual thinkers. The influence of such conceptions has been to block a naturalistic understanding of scientific activity in favor of a set of idealizations. More recently, there has been a healthy backlash against such conceptions. Much modern sociology and philosophy of science now points to the craft and tacit nature of scientific practice, identifies the importance of traditions of practical work, and sees the making of scientific knowledge as a fundamentally social activity (Polanyi 1958; Ravetz 1971; Collins 1985). Put another way, the laboratory is now to be understood more on the model of a workshop and scientists are now to be understood more on the model of technicians.

People who are really present but invisible in an activity are those whose role is considered to be unimportant. In the case of laboratory work, the price of technicians' continued invisibility is an impoverished understanding of the nature of scientific practice.

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