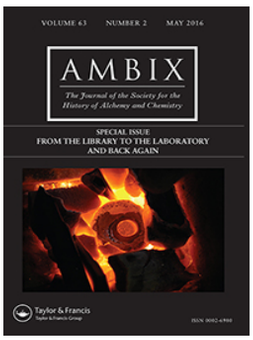

Taylor & Francis
Taylor & Francis Group

Ambix

ISSN: 0002-6980 (Print) 1745-8234 (Online) Journal homepage: https://www.tandfonline.com/loi/yamb20

From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science

Hjalmar Fors, Lawrence M. Principe & H. Otto Sibum

To cite this article: Hjalmar Fors, Lawrence M. Principe & H. Otto Sibum (2016) From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science, Ambix, 63:2, 85-97, DOI: 10.1080/00026980.2016.1213009

To link to this article: https://doi.org/10.1080/00026980.2016.1213009

Published online: 31 Aug 2016.

AMBIX, Vol. 63 No. 2, May 2016, 85–97

From the Library to the Laboratory and Back Again: Experiment as a Tool for Historians of Science

HJALMAR FORS[1], LAWRENCE M. PRINCIPE[2], AND H. OTTO SIBUM[3]

[1] *Hagströmer Library, Karolinska Institutet, Stockholm, and Office for History of Science, Uppsala University, Uppsala, Sweden*
[2] *Department of the History of Science and Technology, Johns Hopkins University, Baltimore, MD, USA*
[3] *Office for History of Science, Uppsala University, Sweden*

Performing experiments is today a well-established tool for exploring the natural world and for increasing our knowledge about it. Although considered a hallmark of what we today call science, practical experimentation has not generally formed a standard part of the methodological tool kit for historians of science. Despite the pioneering work carried out in the second half of the twentieth century, only in the last few years—perhaps as a result of the so-called "material turn" in historical studies—has the topic of reproducing or reworking historical processes and experiments emerged on a larger scale as a complementary means of historical inquiry within the history of science and technology.[1] Indeed, a certain historiographical shift may now be taking place, heralding a broader acceptance and embrace of the methods of reproducing historical experiments and reworking historical practices. Given the notoriety that the method is now achieving, it is worthwhile to

[1] For an introduction to the so-called *material turn* in historical studies, see the recent debate in the American Historical Review: "Historians and the Study of Material Culture—AHR Conversation with L. Auslander, Amy Bentley, H. Leor, H. O. Sibum, C. Witmore," *American Historical Review* 114 (2009): 1355–404. For a sample of current interest in material culture see essays in Pamela H. Smith and Paula Findlen, eds., *Merchants and Marvels: Commerce, Science and Art in Early Modern Europe* (New York: Routledge, 2002); Lorraine Daston, ed., *Things that Talk: Object Lessons from Art and Science* (New York: Zone Books, 2004); Ursula Klein and E. C. Spary, eds., *Materials and Expertise in Early Modern Europe: Between Market and Laboratory* (Chicago: University of Chicago Press, 2009); Paula Findlen, ed., *Early Modern Things: Objects and Their Histories, 1500–1800* (New York: Routledge, 2013); and Pamela H. Smith, Amy R. W. Meyers, and Harold J. Cook, eds., *Ways of Making and Knowing: The Material Culture of Empirical Knowledge* (Ann Arbor, MI: University of Michigan Press, 2014).

DOI 10.1080/00026980.2016.1213009

provide here a concise account of the historical background and historiographical ramifications of this methodology, to outline the various results it can offer historians, and to reflect on how it can answer specific historical questions. By presenting such an account, we hope to help enable the approach to take its place among the accepted and widely used methodologies of inquiry available to historians of science.

A brief history of experimental history of science

Reproducing or reworking experiments is not a recent creation arising from discussions among historians, museum curators, anthropologists, art historians, and others in regard to material culture. Archaeologists have used the method for a long time, such that the term "experimental archaeology" has been coined to describe their investigations that involve reproducing past constructions, artefacts, and processes, some of which—such as those relating to early metallurgy—bear directly on the history of science and technology.[2] Art conservators and art historians likewise have employed the technique for many years to better understand artists' materials, how best to conserve and restore them, and how they were actually produced in the past.[3] Within the history of science and technology too, the performing of past experiments as an adjunct to textual studies has a long history. Much of the early work was done within the history of physics, starting at least in the 1960s with work by Stillman Drake, Thomas Settle, James MacLachlan, and others on Galileo's mechanics as well as by Roger Stuewer on Newton's optics.[4] Other disciplines were not, however, entirely neglected; through the 1950s and 1960s, a seminar on the history of pharmacy held by Wolfgang Schneider at Braunschweig led to several dissertations that included the practical preparation of early chymical pharmaceutical materials according to historical methods as well as the compositional analysis of

[2] For early examples of the term and technique, see Daniel Ingersoll, John E. Yellen, and William Macdonald, eds., *Experimental Archeology* (New York: Columbia University Press, 1977); for more recent work, particularly in the chemical field, see Marcos Martinón-Torres and Thilo Rehren, eds., *Archeology, History and Science: Integrating Approaches to Ancient Materials* (Walnut Creek, CA: Left Coast Press, 2008) and David Bourgarit and Nicolas Thomas, "From Laboratory to Field Experiments: Shared Experience in Brass Cementation," *Historical Metallurgy* 45 (2011): 8–16. See also several excellent examples in Klaus Staubermann, ed., *Reconstructions: Recreating Science and Technology of the Past* (Edinburgh: National Museums Scotland, 2011).

[3] An early example is provided by Daniel V. Thompson, *The Materials and Techniques of Medieval Painting* (New York: Allen & Unwin, 1936). Very interesting work on oils, colours, and artificial gemstones is currently being done by Marjolijn Bol, for example, "Coloring Topaz, Crystal and Moonstone: Gems and the Imitation of Art and Nature, 300–1500," in *Fakes!?: Hoaxes, Counterfeits and Deception in Early Modern Science*, ed. Marco Beretta and Maria Conforti (Sagamore Beach, MA: Science History Publications, 2014), 108–29, and *Oil and the Translucent: Varnishing and Glazing in Practice, Recipes and Historiography, 1100–1600* (Chicago: University of Chicago Press, forthcoming 2017). Large collaborative projects ongoing in the area of art history include Sven Dupré's ERC-funded project "ARTECHNE: Technique in the Arts 1500–1950" at Utrecht University and the University of Amsterdam, and Pamela Smith and co-workers' "Making and Knowing" project at Columbia University, the latter of which centres on editing and following recipes in a sixteenth-century artisan's handbook.

[4] See, for example, the different approaches by Stillman Drake, "Renaissance Music and Experimental Science," *Journal of the History of Ideas* 31 (1970): 483–500, and "Galileo's Experimental Confirmation of Horizontal Inertia: Unpublished Manuscripts," *Isis* 64 (1973): 291–305; Thomas B. Settle, "An Experiment in the History of Science," *Science* 133 (6 January 1961): 19–23, and "La rete degli esperimenti Galileiani," in *Galileo e la scienza sperimentale*, ed. P. Bozzi, C. Maccagni, C. Olivieri, and T. B. Settle (Padua: Dipartimento di fisica Galileo Galilei, 1995), 11–62; J. MacLachlan, "Galileo's Experiments with Pendulums: Real and Imaginary," *Annals of Science* 33 (1976): 173–85, and "Experiments in the History of Science," *Isis* 89 (1998): 90–92; and Roger Stuewer, "A Critical Analysis of Newton's Work on Diffraction," *Isis* 61 (1970): 188–205.

museum samples of such materials.[5] The 1980s and 1990s saw expanded applications of the technique into new areas of inquiry and for answering a range of historical questions. Lawrence Principe reproduced numerous alchemical processes reported by Basilius Valentinus, Robert Boyle, George Starkey (alias Eirenaeus Philalethes), and other seventeenth-century figures, thereby demonstrating that even some seemingly implausible alchemical results could actually be reproduced by circumspect present-day experimentation in a modern laboratory. These results provided powerful evidence for the real—and often difficult or technically sophisticated—laboratory operations carried out by alchemists, and rendered some previous historical claims about the nature of early modern alchemy obsolete. Indeed, Principe's results dramatically refuted a view commonly held at the time that alchemical claims were largely the product of imagination or of merely textual traditions rather than of actual laboratory processes.[6] In the same period, H. Otto Sibum painstakingly reconstructed the apparatus and reworked the nineteenth-century experiments of James Joule to determine the mechanical equivalent of heat. These experiments—focusing as they did on a "canonical" experiment upon which much of present-day physics would rest—uncovered important facts about the social constraints and mechanisms of trust upon which the scientific enterprise depends. Indeed, Sibum established that Joule's crucial experiment could probably not have been reproduced by his scientific contemporaries, since Joule alone combined exquisite experimental technique with relevant artisanal skills that he carried over from his career as a brewer.[7] In the early twenty-first century, these examples were joined by an increasing number of further endeavours; those relating particularly to chemistry include the rebuilding and impressive reworking of Justus Liebig's *Kaliapparat* for the analysis of organic compounds, the reproduction of experiments with a reconstructed ice-calorimeter of Lavoisier and Laplace, and the study of Michael Faraday's early preparations of gold colloids.[8]

[5] The series *Veröffentlichtungen aus dem pharmaziegeschichtlichen Seminar der Technischen Hochschule Braunschweig* includes, for example, Gerald Schröder, *Die pharmazeutisch-chemischen Produkte deutscher Apotheken im Zeitalter der Chemiatrie* (Bremen, 1957); Herbert Wietschoreck, *Die pharmazeutisch-chemischen Produkte deutscher Apotheken im Zeitalter der Nachchemiatrie* (Stuttgart: Deutscher Apoteker-Verlag, 1962); and Erika Hickel, *Salze in den Apotheken des 16. Jahrhunderts* (Braunschweig, 1965).

[6] Lawrence Principe, "'Chemical Translation' and the Role of Impurities in Alchemy: Examples from Basil Valentine's *Triumph-Wagen*," *Ambix* 34 (1987): 21–30; "The Gold Process: Directions in the Study of Robert Boyle's Alchemy," in *Alchemy Revisited: Proceedings of the International Conference on the History of Alchemy at the University of Groningen*, ed. Z. R. W. M. van Martels (Leiden: E. J. Brill, 1990), 200–5; and especially "Apparatus and Reproducibility in Alchemy," in *Instruments and Experimentation in the History of Chemistry*, ed. Frederic L. Holmes and Trevor Levere (Cambridge, MA: MIT Press, 2000), 55–74. See also Lawrence M. Principe, *The Secrets of Alchemy* (Chicago: University of Chicago Press, 2013), esp. 143–66, and "Alchemy Restored," *Isis* 102 (2011): 305–12, esp. 310–11. William R. Newman's forthcoming book, provisionally entitled *Newton the Alchemist* (Princeton: Princeton University Press, forthcoming 2017), deploys reproductions to help understand Newton's thinking about chymistry; see also Newman's "Chymistry of Isaac Newton" website (www.chymistry.org).

[7] H. Otto Sibum, "Reworking the Mechanical Value of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England," *Studies in the History and Philosophy of Science* 26 (1995): 73–106; "Working Experiments: A History of Gestural Knowledge," *The Cambridge Review* (1995): 25–37; "Les gestes de la mesure: Joule, les pratiques de la brasserie et la science," *Annales. Histoire, Sciences Sociales* (1998): 745–74; "Experimental History of Science," in *Museums of Modern Science*, ed. Svante Lindqvist (Sagamore Beach, MA: Science History Publications, 2000), 77–86; and "The Friction of Fluids: Making Sense of Experiment," in *Laboratorium*, ed. Hans-Ulrich Obrist and Barbara Vanderlinden (Antwerp: DuMont, 2001), 244–49.

[8] Melvyn Usselman, Alan Rocke, Christina Reinhart, and Kelly Foulser, "Restaging Liebig: A Study in the Replication of Experiments," *Annals of Science* 62 (2005): 1–55; Peter Heering, "Weighing the Heat: The Replication of the

The recent, almost celebratory, atmosphere surrounding reproducing/reworking historical processes and experiments obscures how controversial such work actually was among historians of science in the fairly recent past. Particularly in the 1990s, the historical technique of reproduction/reworking was often vigorously opposed. Historians who were direct targets of criticism often detected a certain measure of territorialism in the critiques levelled at them; namely, a reflex reaction against what some historians perceived as an incursion by "science" upon "humanistic" turf. Other critics claimed that experimental reconstructions in history of science were relics (or revivals) of positivist approaches, as if those engaged in reproducing past processes believed that their results somehow automatically trumped those arising from more conventional historical sources by giving some supposedly unmediated access to how things *really* happened. In addition to these criticisms from more traditional exponents of the humanities and social sciences, further criticisms originated specifically from strong proponents of the sociology of scientific knowledge (SSK), whose aim was to uncover social, political, and other non-scientific drivers behind scientific claims and thus deconstruct claims for the objective validity of science. Reproduction and reworking—which aimed at understanding more deeply the historical actors, their experiments and ideas and their origins, and which incorporated methods used in the natural sciences—did not always sit well with this agenda of science criticism. If the experimental results of scientists were socially constructed, the argument ran, then the experimental results of historians were no less so, and thus provided information more about the historian than about the original experimenter. Yet such an objection turned out not to be true in practice, and despite such objections, performing historical experiments actually enriched aspects of the sociology of scientific knowledge by illustrating *in practice* how various scientific practitioners relied upon artisans, assistants, and family members, and how scientific work could be embedded in wider artisanal, industrial, and societal networks. Thus, perhaps ironically, experimental reworkers of the 1980s and 1990s were themselves actively exploring the *practice* of science practically and physically, the same topic that their sociologically inclined critics endeavoured to do more theoretically and programmatically.[9] The early practitioners of

[8] *Continued*
Experiments with the Ice-Calorimeter of Lavoisier and Laplace," in *Lavoisier in Perspective*, ed. Marco Beretta (Munich: Deutsches Museum, 2005), 27–41; and Ryan Tweeney, "Discovering Discovery: How Faraday Found the First Metallic Colloid," *Perspectives on Science* 14 (2006): 97–121.

[9] Svante Lindquist, *Technology on Trial: The Introduction of Steam Power Technology into Sweden, 1715–1736* (Uppsala: Almqvist & Wiksell International, 1984); Sibum, "Reworking the Mechanical"; and David Gooding, *Experiment and the Making of Meaning: Human Agency in Scientific Observation and Experiment* (Dordrecht: Kluwer, 1990). In the early 1990s two major exhibitions were staged in Cambridge that centred around reworking experiments: J. Bennett, R. Brain, S. Schaffer, H. O. Sibum, and R. Staley, *Empires of Physics: A Guide to the Exhibition* (Cambridge: Whipple Museum, 1992) and *1900: The New Age* (Cambridge: Whipple Museum, 1994). In 1992, Simon Schaffer, H. Otto Sibum, and Falk Riess organised a major conference "Replications of Historical Experiments in Physics: Their Function in History, Philosophy and Sociology of Science, and in Science Teaching" held at Oldenburg University at which the historiographical issues in reworking experiments were discussed: see Sibum, "Working Experiments" and "Reworking." A further offspring from this conference was *Restaging Coulomb: Usages, controverses et réplications autour de la balance de torsion*, ed. Christine Blondel and Matthias Dörries (Florence: Olschki, 1994). In 1995, a second conference (Rathenau Summer School in Berlin) was convened by Lorraine Daston, Simon

experimental approaches were also engaging directly with the *materiality* of science, and did so, as it now appears, *avant la lettre*. While the subsequent rise of issues relating to scientific materiality has recently brought new attention (and new practitioners) to historical reproductions, this recent surge in interest should be contextualised within the fuller background—methodological, practical, and philosophical—of the history of the technique since at least the 1980s.

The contributions of experimental history of science

Bluntly stated, *the experimental approach is one of many possible historical tools whose purpose is to aid us in our endeavour to understand the past*. It opens the door to a fuller understanding of texts and artefacts through an active engagement with the practices these texts and objects describe or instantiate. Furthermore, it offers fresh and potentially vivid approaches to what historical actors were doing and thinking, as well as why. It responds to the need to extend the historian's analytical repertoire, a need motivated partly by the fact that reading texts about practices can prove frustrating because they rarely provide the information required to fully comprehend the practice involved. The physical engagement with processes or objects of the past provides insights that cannot be obtained simply by reading about them. Experimental reproduction, in short, can help bridge the unavoidable gap that exists between the actions and ideas of historical actors and the textual descriptions or artefactual residues of those actions and ideas that have come down to us. Yet experimental reproductions must be approached with care and historical sensitivity—in fact with the same care and sensitivity needed for approaching a textual or any other traditional historical source. A reproduced experimental process and a text are both potential sources of historical information, but the quality of that information is determined in large part by the quality of the questions asked and the rigour of the interpretations given. Thus, doing good experimental history of science requires the *historical* training that enables one to ask productive *historical* questions. Simply reading original sources and mechanically reworking the experiments therein is never enough, and can lead to results that are uninformed and uninformative—if not entirely misleading. Acuity of questions and proper contextualisation are what make a source—whether textual, experimental, or artefactual—a powerful historical witness.

The experimental approach is thus ultimately dependent on many of the same methodologies needed for more conventional text-based history, and in the best cases there will be a dynamic relationship between library and laboratory. Texts (of various sorts) provide a "first approximation" of the process to be reproduced, and

[9] *Continued*
Schaffer, and H. Otto Sibum entitled "Science and the Knowing Body," at which the question of materiality and embodied knowledge held centre stage; for a major publication see Sibum, "Les Gestes." Usselman et al., "Restaging Liebig," esp. 50–53, uses experimental reproductions explicitly to address contentious issues advanced in the 1990s by sociologists of science, particularly by Harry Collins, *Changing Order: Replication and Induction in Scientific Practice* (Chicago: University of Chicago Press, 1992).

the actual reproduction or reworking then exposes the historian to various sensual experiences, some of which (it is to be hoped) will augment, clarify, or provide fresh insight on the text and its meaning. The improved understanding of the text and practical experience can then be fed back into an improved reworking, and so on. Historians rightly feel very fortunate when the notebooks or diaries of past experimenters exist, but even when highly detailed these textual witnesses cannot provide a full description of past events, and often do not suffice to perform the experiment, let alone to get access to the working knowledge involved.[10] In the majority of cases moreover, such records do not survive, or—particularly as we progress further back in time—may never have existed, and so the historian is left only with a reported result or observation that is more or less well-described.

It is clear that sensual information forms a crucial part of our actors' experiences —sights and colours, smells, sounds, feel, and taste all play an important role, particularly in fields relating to chemistry, which is the science perhaps most closely bound to sensual qualities and their transformations. Yet sensual experiences can be difficult to transmit textually, or are considered matters-of-course by the original practitioners and thus not deemed worthy of being fixed into text, thereby comprising one part of what is widely termed "tacit knowledge." By supplying that sensual data to the historian, therefore, even trivial experiments can sometimes provide striking historical insights. For example, simply witnessing tin and lead melt easily into mobile, silvery liquids and finely divided iron burn brightly in a flame provides experiential background to the long-lived theory of metal composition dating back to the Islamic Middle Ages, namely, that they are composed of mercury (a mobile, silvery liquid) and sulphur (a flammable substance). The sensual experiences of reproducing an experiment can thus offer the historian otherwise unobtainable hints regarding the origins of ideas, theories, conclusions, or the subsequent pathways of investigation followed by historical actors. Such direct experience can also resolve ambiguities or clarify uncertain meanings in textual records, providing a clearer and surer indication of what the author meant. In some cases, the sensual experience reveals an unexpected significance or relevance to what had seemed casual or relatively insignificant remarks in the text. The sensual experience can even assist such otherwise cerebral endeavours as philology. The study in this issue by Moureau and Thomas on cupellation gives an example of how reworking an historical process allowed the authors to understand and correctly translate a passage in a medieval Arabic text that had previously made no sense, and to gain

[10] For two examples, see H. Otto Sibum, "Narrating by Numbers. Keeping an Account of Early 19th Century Laboratory Experiences," in *Reworking the Bench: Research Notebooks in the History of Science*, ed. Frederic L. Holmes, Jürgen Renn, and Hans-Jörg Rheinberger (Dordrecht: Kluwer, 2003), 141–58; and Peter Heering, "Public Experiments and their Analysis with the Replication Method," *Science & Education* 16 (2007): 637–45. Reproducing several of the processes recorded in George Starkey's extant laboratory notebooks gave considerable insight about his results and investigative choices as well as on how best to translate his Latin records into English: see William R. Newman and Lawrence M. Principe, *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry* (Chicago: University of Chicago Press, 2002), on 81, 88 n. 144, 143, and passim; and George Starkey, *Alchemical Laboratory Notebooks and Correspondence*, ed. William R. Newman and Lawrence M. Principe (Chicago: University of Chicago Press, 2004).

insights about the process that were not recorded at all. This and other similar examples clearly demonstrate the *complementary* nature of reproductions and textual analysis.[11] Documentary gaps often exist between texts, and these too can sometimes be bridged by reproduction. For instance, after following George Starkey's early 1650s recipe for "sophic mercury" (needed for making the Philosophers' Stone), Principe discovered that the product grew hot when mixed with gold—a property never mentioned by Starkey, but which indicated that Starkey's recipe was the basis for the "incalescent mercury" cryptically described by Robert Boyle in 1674, thereby linking the two men and providing further documentation about their collaboration.[12]

Visual representations of past experiments, when they exist at all, can be as problematic as textual ones despite their more direct appeal to the sense of sight. Illustrations in scientific publications have a life of their own and do not reveal fully the reality of past laboratory life. Historians have pointed to this fact time and again, particularly when following attempts to historically investigate artisanal knowledge. Kaplan and Koepp, for example, have noted the troubles with the images in Diderot's encyclopaedia, showing how artisans sometimes did not even recognise their own workshop life as it was depicted in the images.[13] A further example is provided by Sibum's initial attempts to build a working replica of a paddle-wheel apparatus originally constructed by Joule. This failed dramatically as long as the reconstruction was based solely on the technical drawing provided by Joule himself and published in the *Philosophical Transactions*. Not even that scale drawing conveyed the necessary information about the mechanical set-up, and only a careful study of the "original" paddle wheel in the Science Museum London allowed for reproducing the mechanical performance described in Joule's publication.[14]

As Ludwik Fleck observed already in the 1920s, the polished literary *Gestalt* of science can differ dramatically from the scientist's lived experience.[15] The resultant disconnect creates fundamental problems in making sense both of specific scientific endeavours and of science as a whole, and hence has become a matter of concern for historians, philosophers, sociologists of science, and scientists themselves. In this regard, reworking or reproducing experiments—as a means of investigating

[11] Similarly, a reworking of an ancient process for making the pigment lead white pointed the way towards a better translation of a problematic Greek verb used by Theophrastus, and showed that previous renderings had failed to capture the technical meaning of term, and hence the actual manipulation that must have been practiced: see Lawrence M. Principe, "Texts and Practices: The Promises and Problems of Laboratory Replication and the Chemical Explanation of Early Alchemical Processes," in *Searching for the Gold: New Perspectives for the Roots of Greek Alchemy*, ed. Efthymios Nicolaidis and Alain Touwaide (Turnout: Brepols, forthcoming 2017).

[12] Lawrence M. Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest* (Princeton: Princeton University Press, 1998), 155–65, esp. 161.

[13] Steven L. Kaplan and Cynthia J. Koepp, eds., *Work in France: Representations, Meaning, Organization, and Practice* (Ithaca, NY: Cornell University Press, 1986).

[14] Sibum, "Reworking," "Experimental History," and "Narrating by Numbers"; James Prescott Joule, "On the Mechanical Equivalent of Heat," *Philosophical Transactions* (1850, Part I); reprinted in *The Scientific Papers*, 2 vols. (London, 1884), Vol. 1, 298–328.

[15] Ludwik Fleck, "Zur Krise der Wirklichkeit," *Die Naturwissenschaften* 17 (1929): 425–30, reprinted in *Erfahrung und Tatsache: Gesammelte Aufsätze*, ed. Lothar Schäfer and Thomas Schnelle (Frankfurt am Main: Suhrkamp, 1983), 46–58.

science as a practice—provides a valuable means of historical investigation. As mentioned above, the physical engagement with historical processes and material objects (or their replicas) provides sensual experiences that enrich the historian's "prior knowledge," that is, the ways of seeing and thinking that a historian brings to a text.[16] Yet even beyond the discrete nuggets of information that can be disclosed, such practical engagement also builds up a working knowledge in the practitioner that Sibum has called "gestural knowledge." If a picture is worth a thousand words, the experience of reworking a process is worth even more. The nature of this gestural knowledge is well-described in his difficult-to-translate German phrase "das in seinen Handlungsvollzug gebundene Wissen."[17] Such *Wissen* further enriches the prior knowledge of the historian, rendering it capable of resembling to a certain extent the working knowledge of the past actors, and thus enabling the historian to "see" in ways more aligned with those of the original experimenters. In this way, the historian obtains a clearer, more vivid sense of actual practices which can prove enlightening in subsequent historical interpretations. By building up the requisite prior knowledge in a historically sensitive way, the acquisition of sensual and gestural knowledge through reproduction/reworking opens the way for a richer, deeper, and more accurate interpretation of textual sources and objects.

The aim of rebuilding a historically accurate prior knowledge does not, however, justify the criticism once levelled at scholars who started reworking or reproducing experiments, namely, that they believed "one could walk the streets of the past again." Reworking/reproducing experiments has unquestionably revealed dimensions of the past—as documented both in this introduction and the papers that follow—that have peremptorially been declared "forever lost."[18] Yet this recovery of "lost" information or practices has been achieved without pretending or needing to transform the historian into some putative member of a past form of life. The above criticism, popular in the 1990s and occasionally still encountered today, arises from an ultimately nihilistic view of the historical enterprise that discards as "impossible" that which is merely difficult; namely, a central endeavour of historical investigation, to learn to see through the eyes and think alongside the minds of past figures to the best extent we can. This endeavour requires patient and constant application, and is continuously honed over a historian's lifetime using whatever tools come to hand. It is no less possible or valuable if it only continues to *approach* its goal without ever fully reaching it. One suspects the criticism

[16] For further reflections on "prior knowledge," see Sébastien Moureau and Nicolas Thomas, "Understanding Texts with the Help of Experimentation: The Example of Cupellation in Arabic Scientific Literature," *Ambix* 63 (2016): 164–83.

[17] Sibum, "Les Gestes," and "Wissen aus erster Hand: Mikro-Dynamik wissenschaftlichen Wandels im frühviktorianischen England," *Historische Anthropologie* 3 (2005): 301–24.

[18] For example, Mario Biagioli, "Tacit Knowledge, Courtliness, and the Scientist's Body," in *Choreographing History*, ed. Susan Leigh Foster (Bloomington, IN: Indiana University Press, 1995), 69–81, calls reworking past experiments and its ambition to reveal the tacit knowledge of past practitioners impossible archaeological feats; for a counter-argument see H. Otto Sibum, "Experiencing Experiment: Gestural Knowledge and Scientific Change in Early 19th Century Victorian Culture" (in Chinese), in "Knowledge: Chinese and Western Thoughts," ed. Zhenhua Yu, *Thought and Culture* 10 (2010): 38–55.

sometimes came from historians who, finding themselves not up to the challenge and rigours of the task, assumed that no one else was capable of it either.

Various methods of experimental history of science and its terminology

Recovering a particular practice from the past does not mean that the historians who reproduce experiments are engaged in the same endeavour as scientists themselves. The reader may have noticed that we have avoided using the word "replication." We have chosen instead the terms "reworking" and "reproduction." Many terms have been used to designate the act of doing experiments as a historian of science and technology, including "replication," "reconstruction," "re-enacting," "restaging," and even, when visits to a particular geographical site is involved, "retreading." These words are all applicable to the endeavour under discussion but are not entirely equivalent in usage. "Reproduction" and "reconstruction" share much in common, although strictly speaking the former focuses predominantly on refollowing or recreating experimental procedures that lead up to the production of specific materials and/or knowledge claims, while the latter generally pertains to the making of objects (although one might reasonably enough refer to "reconstructing a process"). "Reworking," "re-enacting," and "restaging," on the other hand, all place emphasis on the doing rather than on the outcome. Only the term "replication" might be thought to pose a potential problem in the present context due to what has come to be the vexed nature of the notion of replication.[19] But more specifically, we have come to avoid the word because of its particular meanings in modern scientific contexts. In modern science, replication generally means the repetition of an experiment in order to check or confirm prior results. Additionally, in educational contexts students perform canonical experiments in exercises that are often considered to be replications. In that case, successful repetition of canonical experiments is a means of calibrating the mind of the student, generally with the aim of proving particular scientific claims as stated in textbooks.[20] When historians rework or reproduce a process or an experiment as a historiographical tool they are not replicating in these scientific or pedagogical senses, but are instead seeking fresh historical information.

It is certainly not the case that historians are obliged (or even able) to replicate an historical process exactly in order to learn from it. Indeed, there is not a single method for undertaking reproductions—the methodology and degree of similarity to the original historical action should be accommodated to the particular case

[19] For objections to the scientific notion of replication, see Collins, *Changing Order*; but also see Usselman et al., "Restaging Liebig," esp. 50–53, for insightful responses from authors involved in reproducing historical experiments.

[20] On the historical development of the pedagogical use of experiments, see Peter Heering and Roland Wittje, eds., *Learning by Doing: Experiments and Instruments in the History of Science Teaching* (Stuttgart: Franz Steiner Verlag, 2011).

and the questions asked. In some cases, the experience wanted comes from the physical action of repeating the original experiment as exactly as possible. Such research might involve producing a replica of the material set-up and the use of materials as close as possible to those employed in the original experiment. Such work is often a highly interdisciplinary undertaking that involves not only multiple academic disciplines but also the input and expertise of various types of practitioners: scientists, scholars, artists, and artisans. The key subsequent element of such reworking is the performance of the experiment with the replica. This kind of investigation is widely practiced among experimental archaeologists, while the work of Peter Heering on Lavoisier's ice-calorimeter, Sibum on Joule's paddle-wheel, and Usselman, Rocke, Reinhart, and Foulser on Liebig's *Kaliapparat* provide well-documented examples among historians of science.[21] Such undertakings offer the experimenting historian special practical insight regarding the properties, limitations, and ways of handling original construction materials as well as the crucial gestural knowledge connected with a particular instrument, all of which can lead to the uncovering of details, difficulties, and solutions left unrecorded or only hinted at by the original experimenter.

This high level of fidelity to the original process, apparatus, or experimental protocol is not, however, always necessary to carry out a historically informative reproduction. In many cases it is more appropriate to undertake a reproduction by first abstracting what are considered to be (at least in a first approximation) the essential features of the historical process. This approach is especially useful in preparative contexts, where obtaining, explaining, or identifying a particular material product or object is the central goal. Original features which the historian considers to be irrelevant to the final outcome are initially ignored in order to simplify the reproduction. For example, one might use vessels made of modern Pyrex glass instead of early modern soft glass, or employ thermostatically controlled electrical heat sources rather than putrefying dung, or a Bunsen or Meker burner rather than bellows and charcoal, or a starting material obtained from a modern manufacturer rather than something derived closer to the original source. A stripped-down or streamlined version of the process can then be carried out more easily than if a higher degree of "fidelity" were demanded from the outset. If the outcome is not successful, then previously omitted variables can be returned one at a time, and the results reassessed. Clearly this is a laborious and time-consuming process where many failures precede the first (and often limited) success, but it does allow the historian to identify the key variables, often uncovering and identifying unexpected crucial factors in the process. The sequential addition of complexities is one of things that turns the experiment into a learning experience, and sometimes yields the most important results. Indeed, as all of the papers in the present volume illustrate, failures frequently serve to identify the relevant aspects of a past experimental performance. This means that in actual practice, most investigators end up doing a hybrid of reworking

[21] Heering, "Weighing the Heat"; Sibum, "Experimental History of Science"; and Usselman et al., "Restaging Liebig."

and reproduction. As the papers by Fors and Ahnfelt and by Principe illustrate, failures followed by increasingly refined attempts at reproduction engender an increasingly detailed reworking. And as shown by the papers by Robertson and by Moureau and Thomas, reworkers cannot get everything right from the start. Initial trials almost always need to be altered and re-performed in order to obtain the desired results.[22] In this respect, there is little difference between historical reworking/reproduction and the doing of experimental science itself.

Returning for a moment to the educational context, it should be noted that letting students work with replicas of canonical experiments has proven to be a powerful method for them to gain a better understanding of the nature of science in general and the nature of replication in particular. Such deployments have been and continue to be explored by Peter Heering, Elizabeth Cavicchi, and others.[23] Hasok Chang has been one of the most active scholars of late in regard to applying experimental reproductions to the pedagogical realm and in discussing how historical experiments can even function as an important complement to contemporary science.[24] The inclusion of reworkings and reproductions into historical studies also attracts greater attention from scientists themselves, a large and important demographic with which historians of science should endeavour to engage more closely. Several examples of such work have been featured recently in scientific news journals.[25] It is also our experience that the inherent interest of reproducing processes and experiments from the past serves to engage a wider public. Thus historical reproductions/reworkings can also be used to raise the profile and appreciation of our discipline on a broader scale. One must be careful, however, not to fall into a type of "gee-whiz" showmanship, or into a sort of antiquarianism, but rather to explain clearly and demonstrate how such work is embedded in the context of increasing our understanding and appreciation of the historical past.

This issue of *Ambix* consists of four articles, each of which uses reproduction/reworking to answer discrete historical questions, sometimes bringing together historians with archaeologists and scientists. In our choice of subjects, we have chosen

[22] See also Principe, "'Chemical Translation'," 24–25.

[23] In the 1980s the University of Oldenburg reformed physics laboratory classes by replacing modern set-ups of canonical experiments with replicas of the original apparatus. See for example Falk Riess, "Short History of the Use of Historical Experiments in German Physics Lessons," in *Constructing Scientific Understanding Through Contextual Teaching*, ed. Peter Heering and Daniel Osewold (Berlin: Frank & Timme, 2007), 219–26. For the extensive work of Elizabeth Cavicchi at the Massachusetts Institute of Technology, see for example her "Historical Experiments in Students' Hands: Unfragmenting Science Through Action and History," *Science & Education* 17 (2008): 717–49; these pedagogical deployments are in addition to her reworkings of historical experiments, for example, "The Spiral Conductor of Charles Grafton Page: Reconstructing Experience with the Body, More Options, and Ambiguity" in Staubermann, *Reconstructions*, 127–70.

[24] For example, Hasok Chang, "How Historical Experiments can Improve Scientific Knowledge and Science Education: The Cases of Boiling Water and Electrochemistry," *Science & Education* 20 (2011): 317–41; "Chlorine: Undergraduate Research on an Element of Controversy," *Journal of Chemical Education* 86 (2009): 418–20; "Practicing Eighteenth-Century Science Today," in *Nature Engaged: Science in Practice from the Renaissance to the Present*, ed. Mario Biagioli and Jessica Riskin (New York: Palgrave Macmillan, 2012), 41–58; and "History and Philosophy of Science as a Continuation of Science by Other Means," *Science & Education* 8 (1999): 413–25. For an overview of pedagogically-oriented reproduction work see Chang, "Historical Experiments," 318.

[25] For example, *Chemical & Engineering News* 89 (29 August 2011): 40; and 93 (3 August 2015): 35–37.

to illustrate the broad historical range that this approach is capable of addressing. In terms of periodisation and geography, contributions range from tenth-century Arabia and sixteenth- and seventeenth-century England, to seventeenth-century Italy and France, and eighteenth-century Sweden. Topics cover the reworking of a metallurgical process, the protoindustrial production of saltpetre, the reproduction of a chymical wonder, and the making of an early modern medicine. In addition to emphasising the importance of going back and forth constantly between laboratory and library, all the papers underscore the need for careful planning and thoughtful execution of the practical undertakings, as well as the importance of having well-formulated historical questions and hypotheses.

Not every historical project needs or would even benefit from the inclusion of an experimental component, and not every textual process or experiment is worth the often considerable time it takes to rework it. Nevertheless, as we hope to have shown, when potentially enlightening and appropriately framed, experimental reproductions can provide significant new dimensions and insights for historical investigations. The fundamental aim of all experimental activity is to expand the boundaries of what the experimenter knows, and thus when the historian turns to experiment, his or her primary aim is to use experiments to obtain historical information that cannot be accessed by other means or from other sources. The "raw data" thus obtained consists of sensual experience derived from sight, smell, touch, sound and taste, or of gestural knowledge from the engagement of the experimenter's body with the materials or objects under investigation, or of the production and properties of a material or object. The final result can be access to missing information arising from documentary limitations—gaps in laboratory records, the conscious withholding or unconscious omission of information by the original experimenters, tacit knowledge, no longer extant objects or texts, and so forth. Ideally, this information gives us better historical understanding of texts, of practices, of experimental pathways, of practical problems, of the origins of explanations or theories, of historical actors and the nature of their expertise, and of the wider historical and social contexts in which every experimental or artisanal procedure is embedded. The method should serve the purpose of re-evaluating historical episodes and contexts. The aim of this kind of work then is to bring about a synthesis of textual traditions with the sensual and experiential aspects of creating objects, materials, results, and perspectives as part of the historian's pursuit of producing richer, more complete, more compelling historical explanations and narratives.

Acknowledgements

The papers in this special issue were initially presented at a workshop held on 14-16 March 2016 at Uppsala University (Office for History of Science and Division of Pharmacognosy) and at the Hagströmer Library, Karolinska Institutet, Stockholm. The workshop was supported by the Arcadia Fund. The editors also wish to thank

Jennifer Rampling for suggesting a special issue on this topic and for her help and contributions in preparing it.

Notes on contributors

Hjalmar Fors (Ph.D., Docent) is a researcher at the Office for History of Science at the Department for History of Science and Ideas at Uppsala University, and First Librarian at the Hagströmer Medico-Historical Library, Karolinska Institutet. His recent publications include the monograph *The Limits of Matter: Chemistry, Mining, and Enlightenment* (Chicago: University of Chicago Press, 2015). Address: Hagströmer Library, Karolinska Institutet, SE-171 77 Stockholm, Sweden. Email: hjalmar.fors@ki.se

Lawrence M. Principe is the Drew Professor of the Humanities at Johns Hopkins University in the Department of the History of Science and Technology and the Department of Chemistry, and the Director of the Charles Singleton Center for the Study of Premodern Europe. His recent books include *The Scientific Revolution: A Very Short Introduction* (Oxford, 2011) and *The Secrets of Alchemy* (Chicago, 2013). He is currently completing a study of chymistry at the Académie Royale des Sciences, provisionally entitled *Wilhelm Homberg and the Transmutations of Chymistry at the Académie Royale des Sciences*. Address: Department of the History of Science and Technology, 301 Gilman Hall, Johns Hopkins University, 3400 N. Charles Street, Baltimore, Maryland 21218, USA. E-mail: Lmafp@jhu.edu

H. Otto Sibum is Hans Rausing Professor of History of Science and Director of the Office for History of Science at Uppsala University. He is the co-editor of *Histoire des sciences et des saviors, tome 2, modernité et globalization* (Paris: Le Seuil, 2015), and *The Heavens on Earth. Observatories and Astronomy in Nineteenth-Century Science and Culture* (Durham, NC: Duke University Press, 2010). Address: Office for History of Science at the Department of History of Science and Ideas, Uppsala University, Box 629, SE-75126 Uppsala, Sweden. Email: otto .sibum@idehist.uu.se