MATTER AND FACTS: MATERIAL CULTURE AND THE HISTORY OF SCIENCE

Simon Werrett

Revised, January 2104

For inclusion in the collection MATERIAL EVIDENCE: LEARNING FROM ARCHAEOLOGICAL PRACTICE, Edited by Alison Wylie and Robert Chapman.

Department of Science and Technology Studies, University College London, Gower Street, London, WC1E 6BT, United Kingdom

Telephone: ++44 (0)20 7679 3261

Fax: ++44 (0)20 7679 2328

Email: s.werrett@ucl.ac.uk

Word Count: 6440

ABSTRACT FOR ELECTRONIC FORMAT

This chapter explores changing approaches to material culture in the history of science and ways that archaeology and the history of science have served each other in the assessment of historical evidence. Historians have increasingly explored the role of the body, instruments, models, and other materials in the history of science, and use material

re-enactments to learn more about past scientific practices. This work offers archaeologists opportunities to better understand archaeological assessments of evidence. Archaeology in turn offers new ways for historians of science to appreciate the material dimension of science and the places where it is practiced.

ACKNOWLEDGMENTS

Thanks to the editors and all the participants of 2010 Reading conference 'Material Culture as Evidence', to Jenny Rampling, Hasok Chang, and to the members of the Ad Hoc History of Chemistry Reading Group at UCL for their comments and suggestions for this essay.

Historians of science interested in material culture, among whom I would count myself, often gripe about the tendency of other historians to present science as if it was really all about theory, a history of ideas and great geniuses, when really material culture and practice are essential to scientific practice. I assumed, given that material culture is the focus, that archaeologists would share this gripe. So I was surprised to read on the first page of Colin Renfrew and Paul Bahn's textbook *Archaeology Essentials: Theories, Methods, and Practice*, 'The history of archeology is… in the first instance a history of ideas, of theory, of ways of looking at the past' (Renfrew and Bahn, 2007: 13). For a discipline so powerfully evocative of material culture to a novice like me, it was a surprise to find that objects did not figure in this defining statement. Historians of science would today strongly disagree with such an interpretation. They would want to say that ideas and theory are not the only or even principal feature of any science, especially not archaeology!

This is not meant as a rant against archaeology textbooks, but more as an illustration of what the history of science might bring to the table for archeologists. I think the approach of historians of science offers a careful, detailed and ultimately empirical understanding of the history of archeology which avoids grand narratives of continual progress and the evolution of a properly scientific attitude in the discipline. Some studies, such as those of Knossos and the Tomb of Agamemnon by Cathy Gere, have already demonstrated the richness of integrating the two disciplines (Gere 2007; Gere 2011). At the same time, it is abundantly clear that the history of science has plenty to learn from archeology. In recent times, historians have become increasingly interested in the history of the material dimensions of scientific practice and in the use of material culture as a source for historical inquiry. But if historians have embraced material culture as evidence, they have only done so with a relatively limited disciplinary repertoire, which archaeology could greatly enrich. This chapter charts how the history of science has engaged with material culture, and considers how archeological perspectives might expand this approach for both the history of science and the history of archeology.

The chapter begins with a brief exploration of how historians of science shifted from a focus on intellectual history to an interest in the material culture of science in the last decades of the twentieth century. Subsequent sections explore areas of material culture of particular interest to historians of science, and how these have revealed new insights into the nature of scientific evidence and the changing conditions by which evidence is identified, judged, and assessed. Historians have explored the role of the human body in making knowledge and have used re-enactments and re-stagings of past experiments to reveal this. They have investigated how instruments and models came to be regarded (or disregarded) as legitimate sources of scientific evidence, and they have opened up studies of the more general roles material culture play in the sciences. The chapter then turns to an exploration of archeological studies of scientific material culture and identifies some of the ways archaeology might contribute to extending the use of materials as evidence in the history of science.

FROM THE HISTORY OF IDEAS TO EMBODIMENTS OF KNOWLEDGE

Historians of science have always been interested in material culture, but encouraged a more idealist image of science in the middle decades of the twentieth century which the discipline is now trying to move away from. Some of the earliest histories of science considered the material conditions of scientific production. In the eighteenth century, the chemist Joseph Priestley made experiment the object of historical inquiry, cataloguing past experiments in electricity and optics to avoid future research repeating past studies (Christie 1990: 9-10). In the nineteenth century, historians of science included regular references to scientific apparatus in their works, while museum curators exhibited on the history of instruments (Whewell 1837; Anon. 1876).

While curators remained interested in scientific instruments, some historians of science took a more idealist turn in the twentieth century. For some, the Cold War politicized questions about the place of the material in science. In the revolutionary turmoil of the 1920s, the Russian physicist Boris Hessen proposed that scientific theories, in this case Isaac Newton's theory of gravitation, should be understood as products of the economic and social conditions prevailing in a particular time and place, reflecting the Marxist view that culture is a superstructural product of the conditions of production (Hessen 1931). Russian Marxists inspired admirers and critics in the West. Critics countered with an 'internalist' history of ideas in which scientific theories and ideas predominated. Alexander Koyré, a former White soldier in the Russian revolution and a leading light in this more intellectual history, dismissed the Marxist view, ‘I do not see what the *scientia activa* has ever had to do with the development of the calculus, nor the rise of the bourgeoisie with that of the Copernican, or the Keplerian, astronomy’ (Koyré 1968: 6). Ultimately, the progress of ideas was the real key to the history of science.

This emphasis on the history of ideas endured in the history of science through the 1970s. Change came as historians looked to new resources in sociology and anthropology which revived more contextual and social understandings of science recalling those of the Marxists earlier in the century. These inspired more interest in material culture and the study of science as a physical, embodied practice. One resource for this was the ‘Sociology of Scientific Knowledge’ (SSK) arising in the 1970s, which emphasized the ways theories and artifacts were socially constructed by the needs and expectations of communities of interacting users and makers (Law 2010). Some strands of SSK lent particular importance to material culture and practice as evidence. While historians’ evidence base often remained exclusively textual, sociologists went to laboratories and observed scientists as a practice (Latour 1987; Pickering 1992). Historians inspired by SSK followed suite by paying more attention to the physical contexts of past science, wedding this to sociological interpretations of scientific change. For example, in *Leviathan and the Air-Pump* (1985) Steven Shapin and Simon Schaffer explored the rise of experimental science through the career of a seventeenth-century scientific instrument, the air-pump of Robert Boyle, and controversies over its value to science (Shapin and Schaffer 1985).

By the late 1980s, material culture had become a more significant focus for historians of science. In this period, an interest in the context of scientific activity grew into the 'spatial turn', exploring the physical locations and conditions of knowledge-making in laboratories, museums, the field and other sites (Shapin and Ophir 1991; Livingstone 2003). The spatial turn stressed that ideas and theories should be understood as always being embodied in material objects, from human bodies to books, papers, instruments, and other 'immutable mobiles' as sociologist Bruno Latour called them (Law 2010: 181-2). From this point of view, science is less a collection of abstract notions and concepts emerging from the minds of individuals, than a concrete, collective practice of producing, assessing, and circulating material objects designated as carriers of natural knowledge. By the close of the twentieth century, then, many historians came to see science as an embodied practice involving primarily the manipulation of *things*.

BODIES OF EVIDENCE

One of the most important things which do science is the human body, and much recent history of science has been concerned with the role of the body in scientific practice. Bodies are stores of information, gestures, and skills learned over many hundreds or thousands of hours, and ingrained into nerves, muscles and bones. Historically, epistemic judgments have been radically shaped by the capacties and judgments of the human body. As Shapin and Christopher Lawrence have argued, the body of knowledge-makers is intimately tied to their identity, and hence their reliability as truth-tellers, while 'The bodily identity of the truth-seeker undoubtedly varies from culture to culture and from time to time within a culture' (Lawrence and Shapin 1998: 10; Schaffer 1994). The credibility of past evidence hinges on the credibility of those who assess it, and their credit hinges, in part, on their self-representation through bodily form, acts and appearances. The most obvious instance in which embodiment has been linked to epistemic authority is the case of women, who for centuries were excluded from science on the grounds that their bodies disabled them from being reliable truth-tellers in comparison to men (Schiebinger 1989). Male credibility also varied according to bodily forms and gestures. Asceticism, signalled through bodily acts of physical restraint, was long taken to mark a willed disengagement from the world and was associated with the reliable knower, in the figure of the hermit, the chaste or temperate scholar, or the self-effacing seeker of objectivity (Shapin 1998; Daston and Galison 2007: 191-252).

Identifying the embodied nature of evidential assessments has been accompanied by innovative ways of making history more performative. Historians of science now increasingly share with archaeology an interest in re-stagings and re-enactments of past practices as a source of evidence for enriching historical understanding. The extent of these practices has been much greater in archaeology than in history of science. While archaeologists routinely use ethnoarchaeology and ethnographic analogy to see how past techniques might have been achieved, historians of science have only begun relatively recently to engage in similar investigations.

The epistemic status of this work differs in history of science compared to archaeology. While archaeologists have typically framed re-enactments as scientific experiments, occurring within science as a means of increasing knowledge of the past, historians have for the most part framed their re-enactments as historical inquiries into the nature of science itself. Re-enactments in the history of science have a long history (Chang 2011). In the 1960s, Thomas B. Settle of Cornell University investigated Galileo's theories of motion by restaging his experiments (Settle 1961). In the 1990s, Peter Heering used replications to study Coulomb's inverse-square law (Heering 2006; Heering and Witje 2011). Since the early 1990s, H. Otto Sibum has restaged numerous physics experiments from the past including those undertaken by the Manchester physicist James Joule in the mid-nineteenth century to calculate the mechanical equivalent of heat (Sibum 1995). Working from a replica of Joule's apparatus and performing careful re-stagings of Joule's experiments, Sibum revealed how skills were needed to make the experiment succeed which were not widely distributed among contemporary physicists, but which Joule obtained through his experience as a brewer (his family owned and ran a brewery in Manchester). Sibum has highlighted the essential role of 'gestural knowledge' in science, or 'the complex of skills and forms of mastery developed in… real-time performances' in experimentation, and the diverse communities that such knowledge might come from (Sibum 1995: 76). He also reveals an important tension in innovative experiments between the highly individualized skills that may be necessary to make new experiments succeed (in this case Joule's skills as a brewer) and the need for experiments to be sufficiently deskilled to allow them to be replicated by anyone in the scientific community. For those who could not replicate Joule's embodied skills, his experiment did not count as evidence of a mechanical equivalent of heat.

More recently, historians of chemistry and alchemy have turned to re-stagings to make sense of complex chemical and alchemical processes from the past. Jenny Rampling, Lawrence Principe and William Newman, for example, have explored chemical processes and reactions that may have lay behind the recipes of renaissance and early modern alchemical texts (Principe 1987; Principe 2012). Once an historian is able to witness alchemical processes re-created in the laboratory, they argue, the intentional obscurities of alchemical writing may be more easily judged and deciphered. Alternatively, Hasok Chang has used the restaging of past experiments to recover lost knowledge and to explore directions for scientific experiments which earlier investigators may not have taken, an approach Chang calls 'complementary science' (Chang 2004). The emphasis on the material in historiography has thus translated into a growing practical engagement with material evidence as a source for historical research, beyond the traditional emphasis on using texts.

INSTRUMENTS AND MODELS

This historical work shows that in the sciences, evidence needs to be both engaged with the body to be credible and appropriately distanced from it. The body is necessary to make evidence, but if evidence is too embodied in the scientist, or the scientist's body is considered problematic in some way, then the evidence cannot count. This is also apparent in the use of instruments. While historians agonized over the relative merits of intellectual and material history in the late twentieth century, curators working on the history of scientific instruments were already very familiar with issues of material culture and questions of practice and evidence (Van Helden and Hankins 1994; Taub 2011). As interest in material culture grew, so this work became more integrated into the history of science. This work demonstrated that like the body itself, the integrity of instruments plays a critical role in assessments of evidence. What counts as evidence depends on different notions of what count as valid instruments, and how those instruments interact with the bodies of their users. These could differ radically in the past from today. In the seventeenth century, 'philosophical' instruments such as the telescope, microscope, and air-pump were adopted in the sciences because they were viewed as extensions to the senses that would allow humans to restore the extraordinary perceptive powers of Adam and Eve in the Garden of Eden before the Fall (Harrison 2002). Throughout the seventeenth century, debates raged about the validity of instruments as sources of scientific knowledge. Critics rejected the status of microscopic evidence as scientific on the grounds that simply magnifying objects taught nothing about human values, the essential feature of any investigation claiming to be a science (Wilson 1988).

The legitimacy of evidence obtained by instruments is closely related to judgments of the capacities of the human body. In their history of objectivity, Lorraine Daston and Peter Galison have shown how instruments came to be seen in the nineteenth century as a way to remove the body, understood as a repository of weaknesses, personal prejudices and idiosyncrasies, from experimental inquiry. But even this 'mechanical objectivity' did not endure as a credible approach in the sciences (Daston and Galison 2007). In recognition that the human senses could never be entirely removed from acts of observation, some scientists sought to exclude representations and observations entirely from science, in favour of logic and mathematics. Others settled on ‘trained judgment’ or an appropriately disciplined bodily engagement in acts of observation and experimentation, bringing a human expertise into combination with instrumental renderings of natural phenomena. Evidential assessments thus depended on changing ideas of the appropriate interrelation of the body, instruments and objects, and the relative credibility of their different configurations. How these configurations are judged will depend on changing local social contexts and interests.

One consequence of the rise of historical studies interested in materials and practice has been to expand the definition of what counts as scientific material culture well beyond the traditional focus on scientific instruments. Models, for example, have been the subject of many recent studies. Archaeologists have long employed scale models of buildings, ships, cities, sites and excavations to make better sense of them for professionals and the public. Historians dismissed models for a long time as mere teaching aids or museum displays, but as Soraya de Chadarevian and Nick Hopwood have shown recently, scientific models have moved constantly between contexts of research, display, and education and are often crucial to all three (Chadarevian and Hopwood 2004; Maerker 2011; Bud 2013).

Like scientific instruments, the status of models as legitimate sources of evidence has been widely debated in history (Schaffer 2004a). Christopher Evans has drawn attention to the fragility of archaeological models as a form of evidence (Evans 2004). A large watercolour of a ‘druidical temple’ at Mont St Helier, Jersey belonging to nineteenth-century architect Sir John Soane was likely made not from the original site but by copying a model held in the Society of Antiquaries. Evans asks how many other early images of sites of ancient remains were made from models rather than from life? Rusticated textures on stone may be more to do with the cork used to make models than textures on the original stones. Models often existed ambiguously between objective representations and entertaining spectacles in the nineteenth century, deploying lighting effects, magic lantern projections and paintings to give atmosphere and presence to the representation of a site. Models remained prominent in archaeological conference presentations into the twentieth century, shifting from representations of ancient buildings or stone to models of excavations and then reconstructions. Models mediated archaeology to the public, but may also have served to legitimate concepts of evidence in archaeological practice. Pitt Rivers had more than a hundred wooden models of his excavations constructed for public education, and Evans supposes their unprecedented attention to detail reflected, and helped promote, Pitt Rivers' demand for the use of a broader range of evidence in archaeology.

The history of instruments and models demonstrates how the legitimacy of different forms of material culture as evidence in a science may take much time and effort to establish. Lorraine Daston has proposed that a feature of scientific objects is that they are partly defined by the duration and difficulty of constituting them as legitimate objects of inquiry. Daston contrasts the solid 'quotidian' objects of common experience, which 'possess the self-evidence of a slap in the face' with 'scientific objects', typically unfamiliar entities such as atoms, genes, or forces, which take a long time to capture and may or may not prove enduring as things (Daston 2000: 2). More often perhaps, objects may be simultaneously quotidian and scientific, physically robust but fragile in their status as evidence of a theory or interpretation.

NATURE, ARTIFICE AND CULTURE

Historical inquiry thus reveals how the apparently straightforward status of materials and objects as evidence may not have always been so obvious. Another place where this becomes apparent is the boundary between the natural and the artificial, of crucial significance in archaeology. It is a boundary that historians have shown to be changing constantly in history (Newman and Bernadette Bensaud-Vincent 2007). A striking case is provided by a cameo examined by the German monk Albertus Magnus in the thirteenth century, depicting the carefully sculpted heads of two Romans in plumed helmets. As Lorraine Daston has pointed out, while the cameo appears to us as an obviously human artifact, Albertus took it to be a natural object, a product of the personified deity Nature at play (Daston 1998). To see it in this way entailed belonging to a Christian, European culture in which the natural world was the production of a deified Nature acting as vice-regent to the creator God. Cameos, crystals, fossils and other objects were identified as exceptional 'jokes' which Nature created when not producing the normal realm of things (Findlen 1990). Different times and cultures thus draw the boundary of artifice and nature differently. Today changing boundaries are signalled by debates over objects which seem to lie ambiguously between the natural and artificial, such as genetically-engineered organisms, artificial intelligence, or, in the case of archaeology, the 'geofacts' at Pedra Furada in South America (Meltzer 1995).

Recognizing the very different ways that material objects have appeared to scientific inquiry in the past was the goal of a 2004 collection of essays edited by Lorraine Daston entitled *Things That Talk*, which expanded historical studies from a focus on the instruments of scientific inquiry to a broader exploration of certain classes of 'things' in general (Daston 2004). Daston and her collaborators sought in this work to reveal how objects could be the source of multiple meanings and cultural significances, emerging in particular historical moments as evocative and fascinating artifacts. Daston is especially interested in things which bridge the divide between those prompting a singular, unproblematic 'positivist' understanding and those deemed open to endless interpretation, between 'evidence' and 'idol' as she puts it. Such things, with examples including photographs, bubbles, Rorschach tests, and glass flowers, are shown to have evoked new debates and ideas to the degree that their 'thingness' or materiality did not fit into preconceived boundaries and sensibilities. Bubbles, for example, were transformed in the late nineteenth century from transient things into fixed commodities, objects of knowledge, and icons of visual culture. They 'talked' by evoking not only the facts of their constitution but also the renderings of artists, entrepreneurs, and engineers (Schaffer 2004b).

Things That Talk was representative of a new direction in the history of science away from the study of the instruments of science and towards the study of science as one among a variety of artistic, commercial, and technical material cultures. Another work which has been important for developing this approach is the 2010 collection *Materials and Expertise in Early Modern Science*, edited by Ursula Klein and Emma Spary (Klein and Spary 2010; Klein and Lefevre 2007). Like *Things That Talk*, Klein and Spary's collection evokes the diverse meanings given to substances in history, and stresses their location at the intersection of multiple discourses and practices. The authors examine how substances such as dyes, ceramics, milk, ink, spa-water, and gunpowder formed the focus of new interactions between government, the market, consumers and the sciences in the sixteenth to eighteenth centuries, constituting new hybrids of expertise and reshaping knowledge. The approach of this work and Daston's *Things That Talk* has not been without its critics. The historians and curators Thomas Söderqvist and Adam Bencard have criticized Daston for approaching material objects as 'talking', which, even if not meant literally, shifts the focus from the physical to the semiotic in accounting for material objects. This does objects' materiality a disservice by studying it as nothing more than a special version of a text (Soderqvist and Bencard 2010). Nevertheless, the material turn which Daston, Klein, Spary and others have initiated represents a significant shift in the way historians of science have related to material culture.

ARCHAEOLOGY AND MATERIAL HISTORIES OF SCIENCE

Lest it appear that historians have had a lot to say about material culture, it is worth stressing that a great deal of work in the discipline remains focused on the history of ideas, while most of those who have engaged with material culture (including myself) have tended to do so by reading about things rather than engaging with them directly. This is certainly not true of all studies. Museologically-inspired work on scientific instruments, for example, has a long tradition of working with objects (Bennett 1987; Bud 2013). But actual physical and material objects and their properties have not been used as evidence in the history of science as much as might be wished. This is where, I will argue in this final section, archaeology offers great resources for historians to expand their engagements with materials.

Archaeology itself contributed much to the history of science in the twentieth century, particularly in excavations of chemical and alchemical sites in the post-war era. These include the castle of Oberstockstall in Austria, the Louvre in Paris, and the Old Ashmolean in Oxford (Osten 1998; Rouaze 1989; Bennett, Johnston and Simcock 2000; Moorhouse 1972; Anderson 2000; Martinón-Torres 2007). This has revealed information which complements historical research and has offered new insights which textual studies alone could not provide. Scholars such as Robert Anderson have pointed out the value of archaeology in this regard. While drawings and architectural plans can show the situation and arrangement of laboratory spaces, excavations reveal the range and nature of instruments, apparatus, and substances in use inside them (Klein 2008: 775-77). Excavated instruments may also speak of practice in ways that texts cannot. Looking at material objects directly avoids the problem that textual descriptions may be inaccurate because they were copied and distorted over many years. Texts might also be deliberately obscure, as in the case of alchemy. Texts often lack details of structure and process that a direct experience of apparatus makes evident (Anderson 2000: 24). Objects, unlike texts, can reveal their location of origin, showing how materials circulated around Europe (or the world) at different times. The locations of objects also make apparent the kinds of places where they were in use (as Anderson notes, alchemical vessels have typically appeared in excavations of glass-houses, castles, and monasteries, which might not have otherwise been obviously scientific sites) (Anderson 2000: 18). Archaeology reveals further useful information depending on what it fails to find. If certain objects are scarce it may be because they were not as extensively utilized as historians might have thought, based on the textual record. The lack of metal objects in excavations of alchemical apparatus, despite their evident frequency in alchemical texts, suggests that metals were melted down and recycled, whereas glass was cheap enough to throw away and ceramics could not be used again if substances fused into them (Anderson 2000: 25).

The relationship of history of science and archaeology will change as historians and archaeologists reconsider what count as scientific sites. Anderson points out that an adequate history of the chemical laboratory should include not only alchemical or chemical research laboratories but also places of chemical production, testing, and teaching (Anderson 2013: 671-2). Then studies of excavations showing, for example, evidence of glass production for pharmaceutical vessels in Fustat in Cairo become relevant to a history of chemical laboratories, taking that history back much further than is normally the case (Scanlon and Pinder-Wilson 2001; Bacharach 2002). Archaeology may also help to manifest the degree to which past scientific spaces were adapted from existing buildings, changing conceptions of what counts as a scientific space. Kitchens, bedrooms, and cellars in homes in addition to chapels and barracks have all been adapted to undertake experimental research. Excavations might provide evidence of other adapted spaces (Anderson 2013: 673; Werrett 2013).

Archaeology has also helped to reveal the facility and boundaries of past methods of natural inquiry. Recently, Marcos Martinón-Torres from University College London has led a team examining early modern laboratory remains in Europe and America. This work has made manifest the practicality of alchemy and the specific techniques and instruments which it entailed. Martinón-Torres, whose work represents a thoroughly interdisciplinary combination of history of science and archaeology, has shown that alchemy was not just an esoteric search for gold but incorporated mining, assaying and metallurgy more generally. He suggests studies of remains show that alchemists worked with materials previously thought to have only been synthesized in the twentieth century (Pinkowski 2004). Martinón-Torres has also addressed the question of how archaeology and the history of science might be better integrated. He has stressed the value of archaeometric techniques for examining processes of manufacturing and using laboratory instruments, to reveal international networks of production, distribution, and collaboration. He notes that makers' marks can reveal unexpected connections, for example showing combinations of alchemical and freemasonic imagery on early modern objects (Martinón-Torres 2010; Martinón-Torres 2011).

Medical archaeology also provides insights normally overlooked by historians working only with texts. Patricia Baker has pointed to the way archaeology enriches the geography of ancient Roman medicine. While texts may make practices appear homogenous across the ancient Roman empire, excavations provide evidence of regional and local differences. Furthermore, considering contexts where Roman medical instruments have been found discloses much about their non-functional uses. Medical instruments found in rivers and graves suggest their use as votive offerings, samples of property, or as mediating objects between life and death (Baker 2002; Baker 2004a; Baker 2004b). Daniel Antoine notes that medical archaeology also offers a diverse array of resources for understanding the history of epidemics. Archaeological approaches may make possible the identification of disease hosts and vectors, reconstructions of the natural and urban environments and climatic conditions in which diseases spread between individuals, communities, or populations. Archaeology has also identified and dated burial sites of epidemic victims, and sheds light on the material practices and culture around burial or the disposal of bodies (Antoine 2008).

CONCLUSION

These brief examples indicate the potential richness of archaeological approaches for developing further the history of science's engagements with material culture. This chapter has explored how material culture became a focus in the history of science, what historians have been able to learn about the status of material culture as evidence, and how archaeology offers new resources and perspectives for taking these studies further. Historians of science have taken a growing interest in material culture in recent decades. They have shown how changing assessments and constructions of the human body and the material culture of buildings, instruments, models, and other apparatus have been deeply implicated in defining what counts as scientific evidence and how it should be judged. Material evidence is always assessed within a complex of understandings of the nature of materials themselves (as natural or artificial, for example), about the status of materials as valid forms of evidence, and about the bodies of investigators and their credibility in making natural knowledge. These criteria have been constantly changing, so that what might appear as unassailable evidence in one context may soon become irrelevant to scientific knowledge in another. Judgments on all these matters are culturally and historically situated and variable.

If the history of science has highlighted the historicity and fragility of material evidence, it nevertheless has much to learn if it is to fully appreciate the role of the material in the sciences. Against all that fragility is the hard materiality of things themselves. If, recalling the introduction to this chapter, Renfrew and Bahn overplay the significance of ideas in archaeology, then historians of science have surely underplayed the value of archaeology for their enterprise. As historians venture into a more general and broad appreciation of the material in science, archaeology offers them the opportunity to learn beyond the text, revealing new insights into the diverse uses, distributions, circulations and values given to materials and artifacts in the past. If things can talk, archaeology may help historians to listen more closely to what things have to say.

REFERENCES

Anderson, R. G. W. (2000) ‘The Archaeology of Chemistry’, in F. L. Holmes and T. H. Levere (eds) *Instruments and Experimentation in the History of Chemistry*, Cambridge, MA: MIT Press.

Anderson, R. G. W. (2013) ‘Chemistry laboratories, and how they might be studied’, *Studies in History and Philosophy of Science*, 44: 669-675

Anon. (1876) ‘Loan Collection of Scientific Apparatus’, *The Athenaeum*, 2538 (June 17): 832-33.

Antoine, D. (2008) ‘The Archaeology of ‘Plague’’, *Medical History. Supplement*, 27: 101-114.

Bacharach, J. L. (ed.) (2002) *Fustat Finds: Beads, coins, medical instruments, textiles, and other artifacts from the Awad Collection,* Cairo: American University in Cairo Press.

Baker, P. A. (2004a) ‘Roman Medical Instruments: Archaeological Interpretations of their Possible ‘Non-functional’ Uses’, *Social History of Medicine*, 17: 3-21.

Baker, P. A. (2004b) *Medical Care for the Roman Army on the Rhine, Danube and British Frontiers from the First through Third Centuries AD*, British Archaeological Reports International Series 1286, Oxford: Hadrian Books.

Baker, P. A., Carr, G. (eds) (2002) *Practitoners, Practices and Patients: New Approaches to Medical Archaeology and Anthropology*, Oxford: Oxbow Books.

Bennett, J. A. (1987) *The Divided Circle: A History of Instruments for Astronomy, Navigation and Surveying*, Oxford: Phaidon Christie's.

Bennett, J. A., Johnston, S. A. and Simcock, A. V. (2000) *Solomon's House in Oxford: New Finds from the First Museum*, Oxford: Museum of the History of Science.

Bud, Robert (2013) 'Life, DNA, and the Model', *British Journal for the History of Science*, 46: 311-334.

Chadarevian S. de, and Hopwood, N. (eds) (2004) *Models: The Third Dimension of Science*, Stanford, CA: Stanford University Press.

Chang, H. (2004) *Inventing Temperature: Measurement and Scientific Progress. Oxford Studies in the Philosophy of Science*, New York: Oxford University Press, 2004.

Chang, H. (2011) ‘How Historical Experiments Can Improve Scientific Knowledge and Science Education: The Cases of Boiling Water and Electrochemistry,’ *Science and Education*, 20: 317-341.

Christie, J. R. R. (1990) ‘The Development of the Historiography of Science’, in R. C. Olby, G. N. Cantor, J. R. R. Christie and M. J. S. Hodge (eds) *Companion to the History of Modern Science*, London: Routledge.

Daston, L. (1998) ‘Nature by Design’, in C. A. Jones, P. Galison (eds) *Picturing Science, Producing Art*, New York; London: Routledge, pp. 232-53.

Daston, L. ed. (2000) *Biographies of Scientific Objects*, Chicago: University of Chicago Press.

Daston, L. ed. (2004) *Things That Talk: Object Lessons from Art and Science*, New York: Zone Books.

Daston, L. and Galison, P. (2007) *Objectivity*, New York: Zone Books.

Evans, C. (2004) ‘Modelling Monuments and Excavations’, in S. de Chadarevian and N. Hopwood (eds) *Models: The Third Dimension of Science*, Stanford, CA: Stanford University Press, pp. 109-137.

Findlen, P. (1990) ‘Jokes of Nature and Jokes of Knowledge: The Playfulness of Scientific Discourse in Early Modern Europe’, *Renaissance Quarterly*, 43: 292-331.

Gere, C. (2007) *The Tomb of Agamemnon: Mycenae and the Search for a Hero*, London: Profile.

Gere, C. (2011) *Knossos and the Prophets of Modernism*, Chicago: University of Chicago Press.

Harrison, P. (2002) ‘Original Sin and the Problem of Knowledge in Early Modern Europe’, *Journal of the History of Ideas*, 63: 239-259.

Heering, P. (2006) ‘Regular Twists: Replicating Coulomb’s Wire-Torsion Experiments’, *Physics in Perspective*, 8: 52-63.

Heering, P. and Wittje, R. (eds) (2011) *Learning by Doing: Experiments and Instruments in the History of Science Teaching*, Stuttgart: Franz Steiner Verlag.

Hessen, B. (1931) ‘The Social and Economic Roots of Newton’s *Principia*’, in N. I. Bukharin (ed.) *Science at the Crossroads, Papers Presented to the International Congress of the History of Science and Technology Held in London from June 29th to July 3rd, 1931, by the Delegates of the USSR*, London: Kniga Ltd, pp. 149-212.

Klein, U. (2008) 'The Laboratory Challenge: Some Revisions of the Standard View of Early Modern Experimentation', *Isis*, 99: 769-782.

Klein, U. and Spary, E. (eds) (2010) *Materials and Expertise in Early Modern Science,* Chicago: University of Chicago Press.

Klein, U. and Lefèvre, W. (2007) *Materials in Eighteenth-Century Science: A Historical Ontology*, Cambridge, MA: MIT Press.

Koyré, A. (1968) *Newtonian Studies*, Chicago: University of Chicago Press.

Latour, B. (1987) *Science in Action*, Milton Keynes: Open University Press.

Law, J. (2010) 'The Materials of STS', in D. Hicks and M. C. Beaudry (eds) *The Oxford Handbook of Material Culture Studies*, Oxford: Oxford University Press, pp. 173-188.

Lawrence, C. and Shapin, S. (1998) 'Introduction: the Body of Knowledge' in C. Lawrence and S. Shapin, (eds) *Science Incarnate: Historical Embodiments of Natural Knowledge*, Chicago: The University of Chicago Press, pp. 1-20.

Livingstone, D. N. (2003) *Putting Science in Its Place: Geographies of Scientific Knowledge*, Chicago and London: University of Chicago Press.

Maerker, Anna (2011) *Model Experts: Wax Anatomies and Enlightenment in Florence and Vienna, 1775-1815*, Manchester: Manchester University Press.

Martinón-Torres, M. (2007) 'The tools of the chymist: archaeological and scientific analyses of early modern laboratories', in L. M. Principe (ed.) *Chymists and Chymistry: Studies in the History of Alchemy and Early Chemistry*, Sagamore Beach: Science History Publications and Chemical Heritage Foundation, pp. 149-163.

Martinón-Torres, M. (2010) 'Of Marks, Prints, Pots and Becherovka: Freemasons' Branding in Early Modern Europe?' in A. Bevan and D. Wengrow (eds) *Cultures of Commodity Branding*, Walnut Creek, CA: Left Coast Press, pp. 213-33.

Martinón-Torres, M. (2011) 'Some Recent Developments in the Historiography of Alchemy', *Ambix*, 58: 215-237.

Meltzer, D. (1995) 'Stones of Contention', *New Scientist*, no. 1983 (24 June): 31-35.

Moorhouse, S. (1972) 'Medieval distilling apparatus of glass and pottery', *Medieval Archaeology*, 16: 79-121.

Newman, W. and Bensaud-Vincent, B. (eds) (2007) *The Artificial and the Natural: An Evolving Polarity,* Cambridge, MA: MIT Press.

Osten, S. von (1998) *Das Alchemistenlaboratorium Oberstockstall. Ein Fundkomplex des 16. Jahrhunderts aus Niederösterreich,* Innsbruck: Universitätsverlag Wagner.

Pickering, A. (ed.) (1992) *Science as Practice and Culture*, Chicago: University of Chicago Press.

Pinkowski, J. (2004) 'The Alchemist's Lab', *Archaeology*, 57: 26-31.

Principe, L. (1987) ' 'Chemical Translation' and the Role of Impurities in Alchemy: Examples from Basil Valentine's Triumph-Wagen', *Ambix*, 34: 21-30.

Principe, L. (2012) *The Secrets of Alchemy*, Chicago: University of Chicago Press.

Renfrew, C. and Bahn, P. (2007) *Archaeology Essentials: Theories, Methods, and Practice*, London: Thames & Hudson.

Rouaze, I. (1989) 'Un atelier de distillation du moyen age', *Bulletin archeologique du comite des travaux historiques et scientifiques*, 22: 159-271.

Scanlon, G. T. and Pinder-Wilson, R. (2001) *Fustat Glass of the Early Islamic Period*, London: Altajir World of Islam Trust.

Schaffer, S. (1994) ‘Self Evidence’, in J. Chandler, A. I. Davidson, H. Harootunian, (eds) *Questions of Evidence: Proof, Practice, and Persuasion across the Disciplines*, Chicago: University of Chicago Press, pp. 56-91.

Schaffer, S. (2004a) ‘Fish and Ships: Models in the Age of Reason’, in S. de Chadarevian and N. Hopwood (eds) *Models: The Third Dimension of Science*, Stanford, CA: Stanford University Press, pp. 71-105.

Schaffer, S. (2004b) ‘A Science Whose Business is Bursting: Soap Bubbles as Commodities in Classical Physics’, in L. Daston ed. *Things That Talk: Object Lessons from Art and Science*, New York: Zone Books, pp. 147-194.

Schiebinger, L. (1989) *The Mind Has No Sex? Women in the Origins of Modern Science*, Cambridge, MA: Harvard University Press.

Settle, T. B. (1961) ‘An Experiment in the History of Science’, *Science*, 133: 19-23.

Shapin, S. (1998) ‘The philosopher and the chicken: On the dietetics of disembodied knowledge’, in C. Lawrence and S. Shapin (eds) *Science Incarnate: Historical Embodiments of Natural Knowledge,* Chicago: The University of Chicago Press, pp. 21-50.

Shapin, S. and Ophir, A. (eds) (1991) 'The Place of Knowledge: The Spatial Setting and its Relation to the Production of Knowledge', special issue of *Science in Context*, 4: 3-218.

Shapin, S. and Schaffer, S. (1985) *Leviathan and the Air Pump: Hobbes, Boyle and the Experimental Life*, Princeton, NJ: Princeton University Press.

Sibum, H. O. (1995) 'Reworking the Mechanical Equivalent of Heat: Instruments of Precision and Gestures of Accuracy in Early Victorian England', *Studies in History and Philosophy of Science*, 26: 73-106.

Söderqvist, T. and Bencard, A. (2010) 'Do things talk?', in S. Lehmann-Brauns, C. Sichau, H. Trischler (eds) *The Exhibition as Product and Generator of Scholarship*, Berlin: Max Planck Institute Preprint no. 399, pp. 93-102.

Taub, L. (2011) 'Introduction: Reengaging with Instruments', *Isis*, 102: 689-696.

Van Helden, A. and Hankins, T. L. (1994) 'Introduction: Instruments in the History of Science', *Osiris*, 9: 1-6.

Werrett, S. (2013) 'Recycling in Early Modern Science', *British Journal for the History of Science*, 46: 627-646.

Whewell, W. (1837) *History of the Inductive Sciences from the Earliest to the Present Times*, 3 vols, London: John W. Parker.

Wilson, C. (1988) 'Visual Surface and Visual Symbol: the Microscope and the Occult in Early Modern Science', *Journal of the History of Ideas*, 49: 85-108.