Science and the Knowing Body: Making Sense of Embodied Knowledge in Scientific Experiment

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Introduction

In this chapter I am going to investigate science and the knowing body (Plate 10.1). By means of a historiographical approach called 'Experimental History of Science', I will explore embodied knowledge of the past through reworking of historical experiments. However, before we can make sense of embodied knowledge we have to be clear about the role things play in our understanding of the human past. In history and sociology of science this question has been tackled at least since the 1980s when the authors of *Leviathan and the Air-Pump* 'ballasted epistemology with an unknown new actor, a leaky, pieced-together, handmade air pump.' But as the cultural anthropologist Bruno Latour remarked:

'We possess hundreds of myths describing the way subjects (or the collective or intersubjectivity, or epistemes) construct the object – Kant's Copernican Revolution is only one in a long line of examples. Yet we have nothing that recounts the other aspect of the story: how objects construct the subject. Shapin and Schaffer have access to thousands of archival pages on Boyle's ideas, and Hobbes's, but nothing about the tacit practice of the air pump or on the dexterity it required. The witnesses to this second half of history are constituted not by texts or languages but by silent, brute remainders such as pumps, stones and statues'.[1]

Prominent parts of these silent representatives of the past, this second half of history, are stored in museum collections. However, things (and not just those in museum collections) require a thorough practical as well as theoretical investigation in order to understand their role in our attempts of making sense of the world – past and present. For Latour, the state we are in we owe to our modernist thinking that perpetuates the great divide which exists between humans and things and hence tends to silence the latter. Scholars in archaeology, the master discipline of material culture studies, bemoan an asymmetry between things and texts in our reflections about studying the past and in particular how little is done to better understand how objects construct the subject.[2] Since the 1980s historians and sociologists of science have produced remarkable accounts on the investigation of material culture and quite recently general historians have invited a fresh discussion about the potential and limits of studying this second half of human history.[3]

'Experimental History of Science' (EHS) is a program developed in the early 1990s in order to give the endeavour of reworking past experimental practices and their silent representatives of the past a voice.[4] It started off from the still unsatisfactory but already much earlier bemoaned insight that 'When talking of natural sciences, one often forgets that there exists a living scientific practice, parallel to this, an official *Gestalt* of science on paper. These two worlds, however, are frequently as different from one another as are the practice of democratic government and its official theory'.[5]

These two worlds of science, the shiny, polished, enduring one on paper and the rather ephemeral lived practice of science, exist to a large degree still today, and that despite the many efforts to overcome this divide. Hence, EHS aims at studying past science at work. With its approach of building replicas of old scientific instruments and the performance of past trials, it drew attention away from the textual remains of science towards these silent actors, the material culture as well as the scientist's body.

The project began as a pedagogical one in the physics department at Oldenburg University. We wanted to shift physics students' attention away from the polished textbook images and descriptions of canonical experiments to the often messy daily work of a scientist. By replacing modern table-top set-ups of canonical experiments with replicas of the historical ones, we made these students experience physics at work and even prompted them to raise historical questions about their own discipline. This approach soon became labelled the replication method. However, as a historian of science I developed this approach further to a historiographic method emphasising the explorative character of experimentation for historical studies. This diagnostic adventure of past experimental practice I described as reworking rather than replication or re-enactment or reconstruction.[6] When coining the term 'Experimental History of Science' I did so partly in dependence on 'experimental archaeology'.

For the sake of distinction, we may analytically divide this approach into two parts. Firstly, building replicas of historical experiments. The term replica should not be mixed up with the concept of replication, and I will come to that later on. Producing a good copy of an eighteenth or nineteenth-century instrument requires a lot of knowledge and skills in scientific and non-scientific fields. For example, one has to contact craftsmen requesting their expertise about techniques in producing a precision scale or a particular mixture of glass etc. Often these experts are challenged and initially refused to start working on that, because quite often even they themselves did not know any longer how to make such an old device. But after a while these workshop jobs became their most beloved ones, because they were challenging them in a refreshing way, opening up lost dimensions of their own craft and thereby even improving their own field of expertise. In most cases, these craftsmen performed tremendously in producing replicas of the original.[7]

Art curators are equally challenged: For example, Venetian glass vases are difficult to reproduce. By means of using the materials of the historical epoch and his own expertise as a glassblower, the leading expert William Gudenrath was able to obtain new information about the production techniques involved. These acquired skills made him produce replicas that won world recognition, but it should be emphasised that these will never be identical to the originals; they are unique pieces of art.[8]

Secondly, Experimental History of Science comprises performing past experiments with a replica. In science, performing an experiment is understood as replication as scientists try to achieve the same experimental results that were produced in the original experiment. However, it is important to note here, that replication in science does not necessarily mean to use a replica of the original experimental set up. Replication implies first of all to reproduce the same experimental results. Achieving the same results by means of using a very different experimental set up (not a replica of the original device) would even be considered as a much stronger and hence more persuasive replication.[9] Historians of science have taken up the question of replication in a number of different ways. Steven Shapin and Simon Schaffer write for example: 'We had read much about experiment; we had both even performed a few as students; but we did not feel that we had a satisfactory idea of what an experiment was and how it yielded scientific knowledge'.[10] Like anthropologists who perform fieldwork, they studied Robert Boyle's eighteenth-century experiments with an air-pump through the rich textual remains that reveal important dimensions of a famous controversy between Boyle and Thomas Hobbes thereby bringing out excellently the different technologies of knowledge production that determined the course of this controversy, the troubles with replication and how experimental philosophers succeeded in convincing an academic public of the existence of the vacuum as a matter of fact. Peter Galison took up the problem of replication in a different way; he sought to answer historically the question of how an experiment ends. Since there is no unambiguous way to determine when one can consider the replication of an experiment as satisfactory, it is of great importance to learn under which conditions a scientist or a collective decided not to carry out further investigations.[11] David Gooding followed a third way of exploring an experiment, analysing Michael Faraday's extensive laboratory notebook entries line by line in order to derive from them the cognitive processes that led to the development of the electromotor. It must be made clear however that laboratory notebook entries like those of Faraday represent a retrospective consideration of the course of a research day. That is, Faraday's very expressive account indeed offers excellent possibilities for understanding the course of his experimentation, but it should not be forgotten that the textual coherence of the experimental narrative only corresponds in part to the course of past real-time actions.[12]

Performing James Joule's early nineteenth-century paddle-wheel experiment to determine the mechanical equivalent of heat serves as another example. In particular, taking seriously the many painstaking breakdowns in these performances, I have shown that even minute notebook entries of this past scientist do not necessarily yield traces of those experimental techniques I came to recognise as most important in carrying out the experiment. Furthermore, performing the experiment led to the insight that the choreography of actions derived from the publication did not harmonise with the course of action experienced with the replica. Even the sense-economy of the experimenter alone demanded the carrying out of simultaneous working rhythms; an assistant, unnamed in the text, was necessary to manage the mechanical operation of the instrument (Plate 10.2).[13]

Furthermore, a replica constructed according to the scale drawings in Joule's publication did not allow for a repetition of the experiment that corresponded with the results he recorded there. Only further studies on the surviving historical instrument in the Science Museum in London yielded the information that was required to achieve this. Although James Joule himself prepared the illustrations of his apparatus and experimental set-up, these were not sufficiently precise to carry out a successful performance of the experiment. These experienced differences between textual and performative coherence of experimental actions was most annoying but at the same time the source of new discoveries, one of which is that there is a lived practice of science beyond the laboratory notebook narrative which can only be disclosed through performing – or better reworking – the experiment with a replica. I have chosen to speak of 'reworking' experiment rather than 're-enacting' because I want to indicate that every performance of an experiment is a unique event and certainly different from the original one. Hence even if 'reworking' is striving for re-enactment of a past experimental performance, the term 'reworking' serves as a reminder that repetition, replication or re-enactment is impossible. At the most, by means of performance of experiment we are able to reconstruct past events.

In the early 1990s, various historians regarded the performance of a historical experiment with a replica as an ill-conceived approach because this investigation of things could never be acknowledged as a historical source, in fact we were practicing an anachronism.[14] Only gradually they came to realise that they were confusing reworking with replication in the scientific sense. This conflict is still to a certain degree virulent in scholarly discussions. But it is important to understand that reworking past experiments by means of performance is not an attempt to find out 'how it really was'. It is a complementary method to the existing modes of historical exploration that will reveal dimensions of past practice of knowledge-making that are not captured in any literary record of the past and that lead to insights about matters hitherto unrecognised.

In other fields like music or the arts we find similar considerations. The aforementioned glass artist who is today probably the most knowledgeable person about Venetian glass blowing techniques would never claim that he could perform the one and only manufacturing technique as used by Renaissance Venetian glassblowers. Similarly, the director of Academy of Ancient Music and authority in historically informed performance of music, Christopher

Hogwood, always denied that performing historical master pieces of music with historical instruments is a certain way of achieving an authentic historical performance.[15]

Reworking embodied knowledge

What then can reworking of historical experiments be good for? What can it achieve? Although replication is a key methodological component of modern experimental science and broadly understood as a warranty for truth and objectivity, historical studies have shown quite clearly that scientists themselves take rather controversial positions on the meaning of replication.[16] Without going into detail about this aspect here, I would like to stress, however, that employing the performance of past experiments as an instrument for research in the history of science requires a distancing from an understanding of the scientific term 'replication'. Performing historical experiments with a replica is much more than that. It certainly provides deep insight into the process of scientific replication, but in the first instance it is an explorative approach to past practices of knowledge-making that reveals dimensions of the lived practice of science that have not been recorded in our literary remains. In our predominantly literary culture, academic approaches to the lived practice of knowledge-making remain to a large degree within this literary domain. As long as these narratives are exclusively based on observational practices of literary, visual and material sources, these historical accounts may still be insufficient. Only the performance of experiment in combination with the conventional methodological repertoire of textual analysis can unlock and provide full access to a working knowledge that existed in the scientific laboratories, artisanal workshops and studios of the past.

Within conventional history of science, historical investigations of lived practice of past science have merely pointed to the existence of invisible assistants and their embodied knowledge conventionally described as personal or tacit knowledge. Generally speaking, historians know quite a lot about the construction, representation and the disciplining of the human body, but still too little about the productive role of the human body, i.e. the cognitive implications of their bodily disciplining through their engagement in the material world. Reasons for this unsatisfactory situation are manifold and I will just mention the two most relevant ones: Firstly, historians and historians of science have traditionally developed their analytical tools exclusively through engagement with the practices of a literary culture. Despite their increasing interest in the hardware of science or the body techniques of their users, they often lack appropriate diagnostic tools and procedures. Performing past experiments with a replica was initially considered by many as anachronistic and the history of tacit knowledge as a nearly 'impossible archaeological feat because it is usually impossible to go back and find or operate the original instruments in their original settings and setup' – as a historian of science once stated.[17]

Secondly, academic research is still to a large degree part of an influential tradition that defines knowledge as being rational, cerebral, ubiquitous and communicable through texts. Consequently, the implied divide between epistemology and practice leads to a denigration of forms of knowledge, which are embodied, and local. The approach of reworking past experimental practice (EHS) has been developed with the aim of making the impossible archaeological feat possible and to challenge the mentioned epistemological divide. But it is important to mention that this diagnostic adventure is not just drawing the reader's attention away from the software to the hardware of science, rather it uses performance of historical experiments as a technique complementary to conventional historical scholarship. Providing access to these silent representatives of the past and using them in these performances allows for the study of the self-evident gestures at work in the laboratories.

Historians of gesture have pointed to the same methodological problem that they 'cannot walk through the streets of the past in order to observe ordinary situations […] usually

[they] work with incomplete documentation which is more often biased towards the exceptional than to the normal events of everyday life'.[18] Therefore they watch out for sites of social frictions where norms get questioned and self-evident human behaviours become objects of attention and debate.

Complementary to this approach, reworking historical experiments, including the performance of experimental trials, is not dependent on documents of the exceptional. On the contrary, it allows for the investigation of the mundane, self-evident gestures at work in the laboratories of the past. We can study key aspects of the knowing body of the scientist and the changing self-evidence of gestures even of those experiments that were performed in the absence of witnesses.[19]

By means of performing historical experiments with replicas of scientific apparatus and studying their technical breakdowns – the failures – we reveal dimensions of past practice hitherto unrecognised even by the actors themselves or their contemporaries. *Doing* an experiment and recognising the troubles encountered in getting it to work, creates an awareness of the behaviour of the historical experimenter and the unarticulated techniques which were indispensable for the performance of the experiment. Not even in the scientists' notebooks do we find hints about crucial working techniques because these were most often self-evident.[20]

Moreover, reworking past experiments depends above all on the improvisational work and knowledge of the researchers, and the material objects (as well as accompanying texts) serve as a kind of choreography for this performance because they provide partial direction for our thinking and acting. This locally created working knowledge I have termed *gestural knowledge*.[21] The unfamiliar concept will break from the traditional, static concept of disembodiment of knowledge in favour of a conception of knowledge united with the actor's performance of work which changes according to the specific kinds of performance, for example in the manipulation of an instrument or the use of mathematical tools, and in ever new historical circumstances. Therefore, repeating past experiments should not be regarded as showing that they function reliably; reworking aims at exploring the forms of knowing involved in these performances. While in traditional studies knowledge achieved through the use of instruments is simply understood as skills, competences or practices, with the conception of gestural knowledge we succeed in overcoming the fundamental, systematic separation of epistemology and practice which itself has a long historical development. Skills or manual capabilities are now to be considered a constitutive part of the knowledge of the experimenter. What the physical chemist Michael Polanyi once designated as 'tacit' or 'personal knowledge' can be described as the expression of a historically located gestural knowledge, which is historically embodied in the form of the performative actions of the experimenter or in part in the artefacts. And most importantly, their cultural origins can be retrieved. With this dynamic conception of embodied knowledge that is bound to the performative actions of the researcher or collective, we are able to grasp those cultural repertoires of action which are essential for the formation of experimental knowledge but which usually escape the historian's attention because they belong to different worlds of sense, often described as non-verbal or oral knowledge traditions.[22]

Gestural knowledge and scientific change: The case of James Prescott Joule

In order to deepen these reflections, let me refer to an old study of mine, the experimental work of the Victorian brewer James Prescott Joule. His experiment on the determination of the mechanical equivalent of heat is today considered as one of the canonical experiments in physics, because it demonstrated for the first time the existence of a constant relationship between mechanical force and heat that soon became the building block for the science of energy, and energy conservation in particular. Today, in every physics class room, students repeat this experiment and museums display table-top versions in order to illustrate this great achievement in science. And, indeed, visual representations infer that in principle the experiment should work rather easily: You take a pot of water that is stirred through a mechanical device, thereby the liquid gradually warms up. The surprising find is that the ratio of the mechanical work used in order to stir the water and the temperature difference achieved always amounts to the same constant value, called the mechanical value of heat. However, as soon as you perform this experiment with the replica you will notice tremendous troubles in performing it. One of the key experiences in performing this famous experiment is that it requires outstanding thermometrical skills and the construction of extraordinary precision instrumentation (Plate 10.3). No textual remains of this important moment in history of science provide the necessary clues that explain how this was possible**.** Not even in Joule's notebooks will one find any hint, and hence previous generations of historians of science declared Joule's extraordinary experimental achievement a gift of providence. Donald Cardwell, Joule's biographer and outstanding historian of technology concluded: 'In the final analysis I must concede that these particular gifts (Joule's immense skill and precision in performing experiment) were bestowed by Providence and not by his fellow men'.[23]

By studying the material culture of this early Victorian science, we can, however, do better than perpetuating this well known, but highly problematic construction of a genius. The detailed list of troubles that I encountered in practically reworking this early nineteenth-century experiment allowed me to identify hitherto unrecognised connections James Joule was entangled in, that provide explanations as to why he became such a singularly outstanding investigator of nature. We know now that in his work Joule was implicitly drawing on cultural repertoires of action, like his close collaboration with the instrument maker John Benjamin Dancer as well as his upbringing and active participation in the brewing business. Being the son of the wealthiest brewer in Manchester and having worked in that business for more than twenty years (eight hours a day) became crucial in building up thermometrical skills unheard of outside the brewer's world. One should know that in the 1830s brewing had undergone massive transformations in Victorian England, from being a craft tradition to becoming industrial production. This was the place where extraordinary precision techniques, especially in heat measurement, were developed and, more generally, where you learned to trust in numbers.

Similarly important was Joule's close interaction with the leading instrument maker John Benjamin Dancer, with whom he designed and built the most precise thermometer in the country. Joule's active participation in these hitherto unrecognised Manchester subcultures led him to develop this unique calibration technique and his skills in taking heat measurements, which became key in his scientific experiment on the determination of the mechanical equivalent of heat. As I have shown elsewhere, in these informal spaces of learning, Joule acquired a gestural knowledge that would become crucial in the performance of his scientific experiment.[24]

However, this lived scientific practice did not find its representation in the related publication. On the contrary, being a brewer and collaborator with an instrument maker would have made him appear more a member of the Manchester community of skilled artisans rather than one of the established scientific authorities of natural philosophy. Hence, in writing, Joule carefully crafted the official 'Gestalt' of science (as he understood it), because he wanted to be recognised as an authority in natural philosophy. And, indeed, the final publication is a masterpiece in creating this ideal of science: the disembodied observer of natural phenomena and a master of precision measurement. In the published narrative, he made the established fact appear as a constant of nature by effacing all the immense human labour that had gone into the experimental performance. The unskilled working class represented by the unknown brewing mate that had assisted Joule in the mechanical performance of the machine was not mentioned at all. The instrument maker J.B. Dancer, as a representative of the skilled working class, was given the status of a valuable servant. Only Joule himself remained, but now as the disembodied observer of nature who displayed herself. He distanced himself from any kind of sensuous perception other than those gestures of accuracy which demonstrated remote control of the object of research: Reading off temperature scales from the best instrument by means of a 'practiced eye' (Plate 10.4). This would fit the assumed manners of the reader of the *Philosophical Transactions* and was precisely the kind of science that the Cambridge doyen of natural philosophy, William Whewell, who coined the word 'scientist' at this time, helped to promote, the ideal of scientific practice in which sight and hearing were privileged above the other senses. 'The other senses have not any peculiar prerogatives, at least none which bear on the formation of science'.[25]

Moreover, in order to get permission for this text to be printed in the *Philosophical Transactions* Joule even took out the most important theoretical conclusion originally drawn from the experiment, after his referees of the Royal Society questioned its validity. By means of his experiment Joule was convinced that he had deduced that 'friction is the conversion of force into heat' which implied that heat would be an entity that could be transformed into mechanical force and vice versa. This was violating the then accepted theory of heat. Joule did take this conclusion out of the manuscript, not because he was convinced by the arguments of the reviewers, but because he wanted to become an author in this most prestigious journal. The letter from Joule to the Cambridge mathematician G.G. Stokes from the same year of the publication leaves no doubt about this: 'I beg your acceptance of the enclosed paper in which I have endeavoured to determine the mechanical equivalent of Heat with accuracy. The result at which I conceived I had arrived was that Friction consists in the conversion of Force into Heat; but the Committee of the R.S. having disapproved of such a deduction from the experiments I thought it best to withdraw it, although I think this view will ultimately be found to be the correct one'.[26]

Conclusion

In 1934 the French ethnographer Marcel Mauss published an important essay called 'Les techniques du corps', 'Body Techniques', in which he emphasised that 'the physical training of all ages and both sexes is made up of masses of details which pass unobserved; we must undertake to observe them.' As mentioned above, historians and social scientists have taken up his advice and studied the disciplining of the human body in cultural settings. The programme exemplified in this essay is equally inclined to Mauss' work but wants to go a step further. We are not regarding body techniques as representing whole social classes or gender as the notion of *habitus* implies. In our historical anthropological approach, we aim at identifying body techniques of past individuals, but most importantly with the aim to understand the cognitive implications of this bodily formation. The actual performance of a nineteenth-century experiment with a replica has served as the key tool to unlock tacit dimensions of James Joule's experimental practice. Particularly through the various technical breakdowns, this trial became the site of acquiring a gestural knowledge which provided clues to search for hitherto unrecognised historical connections. Through this exploration, the conventional image of this experiment has been challenged. The narrative has provided important insights into hitherto neglected but already existing sites of knowledgeable labour to which Joule had access and which served him as informal spaces of learning. Therefore, this micro study of Joule's experiment provides an explanation of scientific change which acknowledges his singularity and at the same time shows that Joule's mundane self-evident gestures of work and the related embodied knowledge is entangled in a much broader structural development of a web of nineteenth-century practitioners' knowledge. From this perspective, Joule's tacit or personal knowledge is better described as a historically embodied gestural knowledge drawing on cultural repertoires of actions that can be retrieved. In order to gain credit for his achievement, Joule himself shaped his scientific experiment in such a way that his embodied knowledge appeared as an achievement of a disembodied genius. In doing that, he himself reinforced the traditional divide between epistemology and practice and perpetuated the distinction between philosophical authorities and skilled artisans.

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Endnotes

[1] Latour, *We Have Never*, p. 82.
[2] Olsen, 'Material Culture'; Ingold, 'Materials against Materiality'.
[3] See for example Auslander, et al., 'AHR Conversation'.
[4] Sibum, 'Experimentelle Wissenschaftsgeschichte'.
[5] Fleck, 'Zur Krise', p. 50.
[6] Sibum, 'Experimental History'.
[7] For example, a leading German museum asked us whether we would be willing to paint our replica of one their objects in a strange colour, otherwise they would fear that our copy would ruin the market value of the original.

[8] Gudenrath, *Master Class Series*, II: https://renvenetian.cmog.org. Checked on March 4th, 2019.
[9] On replication see Collins, *Changing Order*.
[10] Shapin and Schaffer, *Leviathan*, p. 16.
[11] Galison, *How Experiments End*.
[12] Gooding, *Experiment*; Sibum, 'Narrating by Numbers'.
[13] Joule, 'On the Mechanical Equivalent'; Sibum, 'Reworking the Mechanical Value'; Sibum, 'Experimental History of Science'.
[14] This critique was voiced predominantly orally, but to my knowledge, was never substantiated in print.
[15] Personal communication by Christopher Hogwood to the author.
[16] See for example Collins, 'The Seven Sexes'.
[17] Biagioli, 'Tacit Knowledge', pp. 69-81, 73.
[18] Bremmer and Roodenburg, *A Cultural History*, in particular chapter 6 by Muchembled, 'The Order of Gestures', pp. 129-151, 131.
[19] In contrast to the eighteenth-century understanding of experiment as public spectacle, early nineteenth-century experiments were more and more performed at specially protected locations. In particular, the sensitivity of instruments used in these experiments required special forms of protection and did not allow the presence of witnesses.
[20] James Joule's notebook pages record immense data about the performance of the paddle-wheel experiment. However, as the reworking of the experiment has demonstrated, there is not a single hint to be found on these pages that would reveal knowledge about the most important technique employed in this experiment, i.e. how to perform temperature measurements. See also Sibum, 'Narrating by Numbers', pp. 141-158.
[21] See for example Sibum, 'Reworking the Mechanical'; Sibum, 'Les gestes'.
[22] Polanyi, *Personal Knowledge*; Polanyi, *The Tacit Dimension*.
[23] Cardwell, *James Joule*.
[24] Sibum, 'Les gestes'.
[25] Whewell, *The Philosophy*, Vol. 1, p. 280.
[26] Joule to Stokes, July 3rd, 1850, Cambridge University Library, ADD.