The stabilization of experimental procedures: Historical and educational aspects

A estabilização de procedimentos experimentais: aspectos históricos e educacionais

PETER HEERING

University of Flensburg | Germany

ABSTRACT This paper addresses the development of experiments and experimental practices in the process of transformation from a unique and innovative research experience towards established knowledge. In this respect, some strategies of stabilization will be discussed in an exemplary manner, using examples from 18th century research in the field of electricity. Moreover, some educational implications of this process will also be discussed.

Keywords history of scientific experimentation – experimental practices – science education.

RESUMO *Este artigo trata do desenvolvimento de experimentos e práticas experimentais no processo de passagem de uma experiência de pesquisa singular e inovadora para um conhecimento estabelecido. Nesse sentido, algumas estratégias de estabilização serão discutidas de maneira exemplar, usando casos da pesquisa setecentista no campo da eletricidade. Além disso, algumas implicações educacionais desse processo também serao discutidas.*

Palavras-chave *história da experimentação científica – práticas experimentais – educação científica.*

In 1746, the English natural philosopher William Watson wrote two letters to Martin Folkes, at the time President of the Royal Society London. In these letters, he described an electrical experiment which he had been able to replicate:

> *I suspended a Poker in silk Lines; at the Handle of which hung several little Bundles of white thread, the Extremities of which were about a Foot at right Angles from the Poker. Among these Threads, which were al attracted by the rubbed Tube, I excited the greatest electrical Fire I was capable, whilst an Assistant near the End of the Poker held in his Hand a Spoon, in which were the warm Spirits. Thus the Thread communicated the Electricity to the Poker, and the Spirit was fired at the other End. … By these Means, I fired several Times not only the ætherial Liquor or Phlogiston of Frobenius and rectified Spirit of Wine, but even common proof Spirit.*[1]

In a second letter to the Royal Society, Watson gave a modified description of this experiment:

> *I placed a Man upon a Cake of Wax, who held in one of his Hands a Spoon with the warm Spirits, and in the other a Poker with the Thread. I rubbed the Tube amongst the Thread, and electrified him as before. I then ordered a Person not electrified to bring his Finger near the Middle of the Spoon; upon which, the Flash from the Spoon and Spirit was violent enough to fire the Spirit.*[2]

This experiment, the electrical ignition of fluids, was amongst the most popular ones in the popular area of 18th century electricity. Initially, this experiment had been carried out by the physician C. F. Ludolff in January 1744[3] and it became fairly quick part of the standard repertoire of those instrument makers and demonstrators who showed electrical experiments (at least according to their publications). Several of these publications demonstrate the prominence of this experiment by including a plate which shows how the experiment is to be performed, and from these plates, some modifications get visible.

Figure 1: Electrical ignition of a liquid with a rapier.[5]

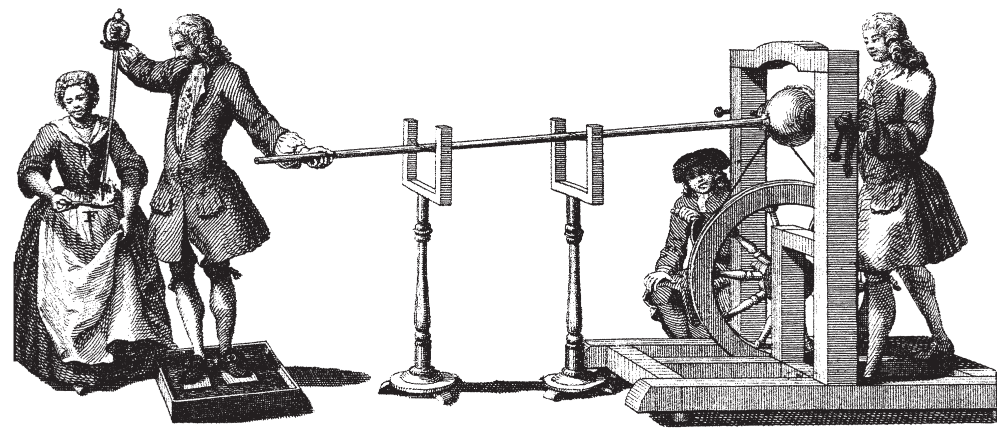
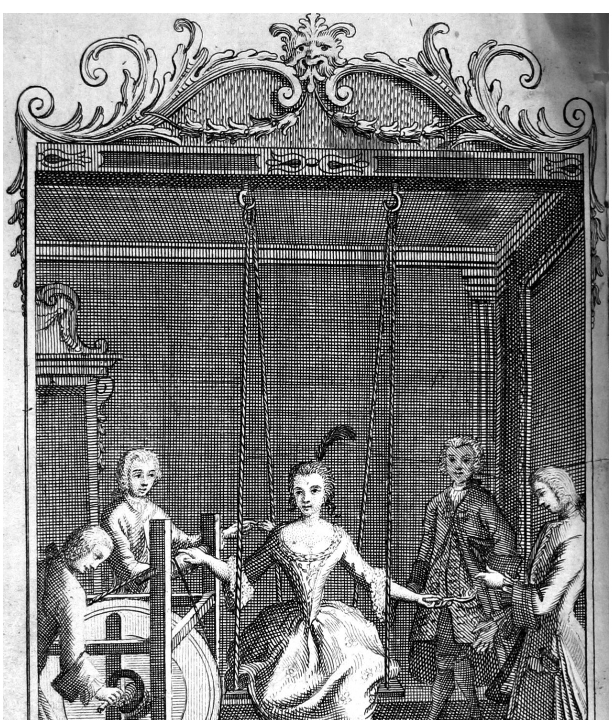


Figure 2: Electrical ignition of a liquid with a finger.[6]



To start with one example: Figure 1 shows one of the classical performances of the experiment: One person stands insulated and is in contact with the prime conductor of the electrostatic generator (that may also be a poker as described by Watson). Another person presents a spoon with the ignitable liquid, and the first person approaches the surface of the liquid with a rapier. When a spark flies from the end of the rapier into the liquid, the liquid will be ignited. As already mentioned, this was one of those experiments which were very popular, and in the process of demonstrating the experiment, several modifications took place. One of the most notable ones was realized by Johann Heinrich Winkler, a demonstrator who established himself in Leipzig and became – at least in part through the popularity of his public lectures – one of the leading electrical researchers in the German speaking community. Winkler performed his experiment publicly. At one of these occasions, in the presence of Christian Wolff, the leading German authority in natural philosophy, he was requested whether the metal was really necessary in order to ignite the liquid. According to his account, Winkler had to admit that he was not aware whether this was a requirement, thus the audience tried the experiment without the rapier, and again, the liquid burned.[4]

However, let us return to the letter William Watson wrote in order to inform the Royal Society about his experiments: what makes his report and noteworthy is not that he described the experiment – even though he is one of the first in England to describe this experiment. Remarkable appears the introduction of his first letter:

> *The Society having heard from some of their Correspondents in Germany, that what they call a Vegetable Quintessence had been fired by Electricity, I take this Opportunity to acquaint you, that on Friday Evening last I succeeded, after having been disappointed in many Attempts, in setting Spirits of Wine on Fire by that Power.*[7]

The unusual part in his account is the admittance of a large number of unsuccessful attempts. This is a detail which is not found in that many descriptions of experiments, the majority reads as the following example from a book on popular experiment by George Ribright:

> *To set Spirits of Wine on Fire. If some warm spirits of wine be brought in a cup, within the reach of the person standing on the stool, and he presents his finger perpendicularly down near the spirits, the spirits will immediately take fire; and, in a like manner, if the cup, provided in the apparatus, be fixed on the prime conductor (as in plate II, fig. 14) any one in the room, not on the stool, nor in connection with the prime conductor, by putting his finger to the spirits, as in plate, will set them on fire.*[8]

Comparing the two accounts, different rhetoric figures get evident: Watson is claiming that it took him many attempts before he finally succeeded with the experiment. From this description, an image of the experimenter is created where Watson had to overcome many disappointments, and where the final success in the experiment forms a significant achievement. However, in Ribright's account, the image of the experimenter is completely different – here "any one in the room" will set the liquid on fire.

Even though one could discuss the different images of the experimenters that are created by these two accounts, this is not my concern in this paper. What appears more relevant is the discussion of the experiment itself, and of the change that took place between Watson's account and Ribright's.

To Ribright, the experiment is no longer problematic, it can be demonstrated at will – actually it is no longer open with respect to the outcome. This is different with respect to the situation of Watson – he has only heard about the experiment and he is not aware of the precautions that one may have to take in order to perform the experiment with the anticipated outcome. Consequently, Watson is forced to vary the procedures, maybe also the materials, in order to find the appropriate manner of performance of the experiment. This is an approach which is very typical for experimental situations: an experimenter has a notion what the outcome of the manipulation of the experimental set-up should be, and she or he is trying to meet the required combination of instrumental arrangement and performative procedures.[9] Once this process has succeeded, in many cases the experiment is repeated in order to be stabilized – during this process, the experiment loses flexibility and gains reliability. In the end, the experiment is in a status that is demonstrated by Ribright's description – everyone can do it. However, at the same time, the meaning of the experiment has been modified – it is no longer used to produce new knowledge, but it serves to the demonstration of established knowledge (or entertainment through established knowledge).

Through this stabilisation process, knowledge can be generated that goes beyond the individual experiment. To give but two examples: In 1747, John Neale published a monograph which aimed at giving advice to – as Neale put it in the title – *Gentlemen, who have Electrical Machines, how to proceed in making their Experiments*. In this monograph Neale identified in his introduction several procedural steps which an experimenter should follow prior to the experimentation in order to have the instrumental set-up in a most appropriate state:

> *When the machine is to be used, the globe or spheroid should be first wiped clean with dry warm linnen cloth, its pivots oil'd, and the string duly stretched on the wheel. The rubber, or cushion should be likewise warm'd*

at the fire, but not so much as to bring out any greasiness to the surface of the leather; and if the weather be damp, or pretty cold, it will be necessary to have a fire in the room not far from the machine.[10]

Neale's interest in passing this information to his readers is evident from his publication as he also included an advertisement in his book that he made and sold all kinds of electrical machines.

But it is not just the instrumentation or the manipulation that needs to be controlled in several experiments but also the environment:

When the air is dry, particularly when there is a frost, and the wind is north or east, there is scarce any electric machine but will work very well. If the air be damp, make a large fire in the room where the machine stands, and let the globe, and every thing about it, be made very dry: it will then work almost as well as in the best state of the air.[11]

The author, Hooper, is referring neither to the machine nor to the actions of the experimenter, but to the environment that also needs to be controlled in a specific manner. Thus, the required control in the stabilization of the experimental situation is not just limited to the instrument and the experimenter's actions but also the environmental conditions are to be controlled. When looking at the literature on this experiment, however, one cannot fail to notice that only very few accounts mention any of these control measures that are to be taken in order to make the experiment work. Most accounts are given in a manner that corresponds to the example of Ribright – the experiment is fail-proof, everyone can do it. One can argue that this is understandable as an account of an experiment normally addresses researchers who have an expertise in the respective field. In this respect, it is understandable that Hooper as well as Neale explicitly mention these precautions – their publications address amateurs, gentlemen who want to carry out experiments.

Yet, there appears to be one detail that deserves some attention: These necessary precautions and measures in order to stabilize the experimental situation were well known to the practitioners in the historical situation. However, it is evident that this knowledge is not time-independent. Therefore, researchers in the 21st century clearly have knowledge different to that of practitioners from the 18th century, and particularly with respect to practices, there has not only new knowledge (additionally) been produced, but also knowledge modified and even lost. Consequently, what appears to be a simple and straightforward experiment according to the description turns out to be difficult when the implicit knowledge that is connected with the experiment does not exist anymore.

Despite the recently developed awareness in historical studies of the importance of skills and tacit knowledge, there appears to be at least one area where this relevance is still underestimated: In science education, we still find accounts on experiments that resemble very much the Ribright's description – the experiment is so easy that everyone in the room can do it. Moreover, there are several historical experiments that are commonly used for educational purposed, and the description of these experiments follows also the line of argumentation – experiments are easy to be carried out, there is no other possible result, and the outcome is straightforward. Thus, the discussion of historical experiments in textbooks is not only to be criticized as the account of the experiments is inappropriate with respect to historical details,[12] but also with respect to the understanding of experimentation. In this respect, despite the fact that aspects from the nature of science have received significant attention in science education during the last decades, the nature of scientific experimentation appears to be still widely ignored with respect to educational approaches. Experimental practice is still described as being more or less simple: in most cases, the experimenter is not part of the experiment, but a virtual person seemingly carries out the manipulations of the apparatus. Moreover, the image created in the educational context can be characterized as follows: the experimental procedures appear to be straightforward and unproblematic, a successful experiment is neither the result of a stabilisation process nor the outcome of a social discourse. Through this textual representation of scientific experimentation, an image is created where only an incompetent experimenter may produce erroneous results.[13]

This misleading image of scientific experimentation shall be illustrated with another example: Coulomb's work on the force-distance relation in electrostatics. This relation (or in most cases actually Coulomb's Law) is mentioned together with Coulomb's experiment in a large number of modern textbooks. In 1785, Charles Augustin Coulomb, a French military engineer started to carry out electrical experiment with the torsion balance he had developed. The first publication with this instrument was an experimental demonstration of the inverse square force distance relation in electrostatic repulsion.[14]

Instead of referring to modern textbooks, let me use the characterization of a historian to illustrate the classical image of the experiment:

> *Clearly this was a discovery of the first importance, but it needed confirming by measurements of the utmost precision. It was the Frenchman Charles Coulomb, a physicist and engineer, who managed to achieve the necessary accuracy in 1785 with his 'torsion balance'. ... Ingenious and elegantly simple, like all the best experiments, the balance was very sensitive and allowed Coulomb to prove that not only electrical charges but also magnets attracted each other with a force that did vary precisely according to the square of the distance between them.*[15]

Particularly the characterization of the experiment as being "ingenious and elegantly simple" produces an image that is misleading.[16] When looking at the historical situation, it gets evident that the experiment was probably not simple:[17] In the German speaking areas, several scholars rejected Coulomb's work and advocated a different law in order to describe the force distance relation in case of electrostatic repulsion.[18] Even though there were conceptual aspects involved, there was also skepticism against the reliability of the torsion balance. One protagonist of this discussion, Paul Louis Simon, develops a different instrument for obvious reasons:

> *While lecturing on electricity a year ago, I already began to think about how to conduct experiments on electrical repulsion in such a way that Coulomb's compound torsion apparatus, which fluctuates too heavily for use in lectures, would not be necessary.*[19]

The lack of stability of the torsion balance experiment gets also evident from the contribution of Peter Nikolaus Caspar Egen, a mathematician who was supporting Coulomb's work and brought the discussion on the force-distance relation almost to an end. Nevertheless, even in Egen's work the difficulties several researchers experienced in working with the torsion balance get evident:

> *But it is quite natural that Coulomb made more precise observations with his torsion balance than other physicists. Coulomb had excellent observational skills, which, as with all other intellectual gifts, come from heaven. The torsion balance was Coloumb's child, and, indeed, his most cherished child… He knew how to adjust it so as to avoid the most miniscule outside disturbances ...*[20]

In Egen's statement, the necessity of stabilization of an experiment gets obvious again – evidently, in the German speaking community this process had not been completed. Consequently, the image of the experiment Egen is creating in his account differs significantly from those of later textbooks or historians' accounts. According to Egen's description, it requires particular abilities in order to manage the performance of the instrument, and it is necessary to control all the external influences in order to come to a reliable result. Yet, when looking at modern textbook accounts of this experiment, the precautions, the necessity of skills and the required control have vanished. Moreover, there exist modern educational set-ups which are labelled to enable lab practices that easily show the force-distance relation. Evidently, these educational set-ups are realized in a manner that the experimenter needs limited skills, part of the precautions are already materialized in the instrument.[21]

Both cases demonstrate that experimenting is a process that is more complex than most textual accounts seem to indicate. Particularly the process of stabilizing experimental procedures, and thus controlling the experimental outcomes, deserve more attention than they have received so far. This is the case for historical accounts of scientific experimentation. However, it is also relevant for purposes where historical materials are used in science education. Particularly in this respect it appears to be relevant to enable students to come to a better understanding of the modifications an experiment experiences when being transformed from the process of producing new knowledge to the demonstration of this acquired knowledge.

Notes and references

Peter Heering is Professor of the History and Didactics of Physics at the University of Flensburg, Germany. E-mail: peter.heering@uni-flensburg.de.

1 WATSON, William. *Experiments and observations tending to illustrate the nature and properties of electricity: in one letter to Martin Folkes and two to the Royal Society. By William Watson*. 2nd Ed. London: C. Davis, 1746. p. 6.

2 Idem, p. 11.

3 HEILBRON, J. L. *Electricity in the 17th and 18th Centuries: A Study in Early Modern Physics*. Reprint with additions (initial publication 1979). Mineola: Dover, 1999.

4 HOCHADEL, Oliver. *Öffentliche Wissenschaft: Elektrizität in der deutschen Aufklärung.* Göttingen: Wallstein, 2003. See also Figure 2.

5 From DESAGULIERS, J. T. *De natuurkunde uit ondervindingen.* Vol. 2. Amsterdam: Isaak Tirion, 1751. With permission of the Landesbibliothek Oldenburg.

6 From SGUARIO, Eusebio. *Dell' elettricismo: o sia delle forze elettriche de' corpi svelate dalla fisica sperimentale : con un' ampia dichiarazione della luce elettrica, sua natura, e maravigliose proprietà; aggiuntevi due dissertazioni attinenti all' uso medico di tali forze.* In Napoli: A spese di Giuseppe Ponzelli. Nella stamperia di Giovanni di Simone, 1747. With permission of the Bakken Library and Museum Minneapolis.

7 WATSON, op. cit., p. 4. Watson is not the only one who encountered difficulties: "Gralath, who learned of Ludolff's success before learning the experimental details, could not repeat it …", according to HEILBRON, op. cit., 1999, p. 273.

8 RIBRIGHT, G. *A Curious Collection of Experiments: To Be Performed On the Electrical Machines, Made By Geo. Ribright and Son, (no. 40,) in the Poultry, London.* London: J. Brown, 1779. p. 5.

9 In this respect, the experimental procedure is significantly different from Steinle's concept of explorative experimentation where a theoretical knowledge needs to be generated in the course of the experiments. See STEINLE, Friedrich. *Explorative Experimente: Ampère, Faraday und die Ursprünge der Elektrodynamik.* Stuttgart: Steiner, 2005, and also RIBE, Neil; STEINLE, F. Exploratory Experimentation: Goethe, Land, and Color Theory. *Physics Today*, v. 55, n. 7, p. 43-49, 2002.

10 NEALE, John. *Directions for Gentlemen, who have Electrical Machines, how to proceed in making their Experiments.* London: Printed for the Author, 1747. p. 4. An identical description can be found in WATKINS, Francis. *A particular account of the electrical experiments hitherto made publick: with variety of new ones, and full instructions for performing them : to which is annex'd the description of a compleat electrical machine, and its apparatus, with the way of using it.* London: Printed for, and sold by the author ..., 1747.

11 HOOPER, W. *Rational Recreations: In which the Principles of Numbers and Natural Philosophy are clearly and copiously elucidated, by a Series of Easy, Entertaining, Interesting Experiments. Among which are all those commonly performed with the Cards.* 2nd Edition. London: L. Davis; J. Robson; B. Law; G. Robinson, 1783. p. 16.

12 See e.g. HEERING, Peter; KOWALSKI, Sebastian. Not out of the Blue – The Genesis of Modern School Science Textbook Descriptions of Historical Experiments. In: ROCA, A. R. (Ed.). *The Circulation of Science and Technology: Proceedings of the 4th International Conference of the ESHS, Barcelona, 18-20 November 2010.* Barcelona: Societat Catalana d'Història de la Ciència i de la Tècnica, 2012; KLASSEN, Stephen; NIAZ, Mansoor; METZ, Don; McMILLAN, Barbara; DIETRICH, Sarah. Portrayal of the History of the Photoelectric Effect in Laboratory Instructions. *Science & Education,* v. 21, n. 5, p. 729-743, 2012; and NIAZ, Mansoor; RODRÍGUEZ, María. The Oil Drop Experiment: Do Physical Chemistry Textbooks Refer to its Controversial Nature? *Science & Education,* v. 14, n. 1, p. 43-57, 2005.

13 For a discussion of students conception of errors see HEINICKE, Susanne; HEERING, Peter. Discovering Randomness, Recovering Expertise: The Different Approaches to the Quality in Measurement of Coulomb and Gauss and of Today's Students. *Science & Education,* v. 22, n. 3, p. 483-503, 2013.

14 COULOMB, Charles Augustin. Premier mémoir sur l'électricité et le magnétisme. *Mémoires de l'Academie Royale des Sciences pour l'Année 1785,* p. 569 – 577, 1788.

15 RONAN, Colin A. 1984. *The Cambridge Illustrated History of the World's Science.* Vol. 2. Cambridge: Cambridge University Press, 1984. p. 382.

16 I am not going to address the detail of Ronan's claim that Coulomb did prove with the torsion balance that electrical charges attract each other with a force that did vary according to the inverse square of the distance between the charges. Apart from the fact that the balance did hardly work for the case of attraction (as Coulomb pointed out at the beginning of his second memoir on electricity), one can question whether the experiment did actually prove the relation.

17 From the experiences that were made during the analysis with the replication method, it also became evident that operating the torsion balance is by no means. See HEERING, Peter. The replication of the torsion balance experiment: The inverse square Law and its refutation by early 19th-century German physicists. In: BLONDEL, C; DÖRRIES, M. (Eds.). *Restaging Coulomb: Usages, Controverses et réplications autour de la balance de torsion.* Firenze: Leo S. Olschki, 1994. For additional experiences, see MARTÍNEZ, Alberto A. Replication of Coulomb's Torsion Balance Experiment. *Archive for History of Exact Sciences,* v. 60, n. 6, p. 517-563, 2006; SHECH, Elay; HATLEBACK, Eric. The Material Intricacies of Coulomb's 1785 Electric Torsion Balance Experiment.

Historical Studies in the Natural Sciences, under consideration, 2013; and HEERING, Peter. Revisiting Coulomb's Torsion Balance Experiment. *Historical Historical Studies in the Natural Sciences,* under consideration, 2013.

18 For this discussion see HEERING, op. cit., 1994.

19 SIMON, Paul Louis. Auszug aus einem Schreiben ... an den Professor Gilbert in Halle. *Annalen der Physik,* v. 27, p. 325-327, 1807. p. 325.

20 EGEN, P. N. C. Ueber das Gesetz der elektrischen Abstoßungskraft. *Annalen der Physik und Chemie,* v. 5, p. 199-222, 1825. p. 215.

21 The attempt to materialize skills is not limited to modern educational set-ups, a comparable instrumental development can be identified in case of the solar microscope – see HEERING, Peter. Materialised skills: Instrumental development and practical experiences. In: STAUBERMANN, K. B. (Ed.). *Reconstructions: recreating science and technology of the past.* Edinburgh: NMS Enterprises, 2011.

[Recebido em Outubro de 2014. Aprovado para publicação em Novembro de 2014]