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THE ROLE OF HISTORICAL EXPERIMENTS IN SCIENCE TEACHER TRAINING: EXPERIENCES AND PERSPECTIVES

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Summary: *In this paper, I am going to discuss several aspects of the approach that has been applied in the physics teacher education at the University of Oldenburg for almost 25 years.*[1] *My aim is to show that history of science can play an important role in science education, and that both fields —science education and history of science— can mutually benefit from each other. In doing so, I will briefly sketch methodologically what we are doing in our group with respect to historical research. In the next step, I will discuss how historical experiments can be implemented in science teacher training and what can be achieved with such an attempt. In doing so, I will discuss in detail a compulsory course for future physics teachers and will highlight two examples. Finally, I am going to argue that also history of science as an academic discipline could benefit from a collaboration with science education.*

Key words: *science teacher training, nature of science, historical experiments, replication method, Coulomb's law, eriometer*

1. The historical oriented programme in teacher training at the university Oldenburg was started by Falk Rieß and some of his colleagues in the 1980s, several structural aspects of this programme are discussed in (Rieß, 1995; 2001). The use of historical experiments in science education was already advocated in the early 1970s, see (Devons & Hartmann, 1970). In Germany, this approach was also fostered in particular by (Teichmann, 1979; Achilles, 1996; Wilke, 1987). Except for the Oldenburg programme, all of these German approaches were already terminated.

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Introduction

History of science has frequently been advocated as being an enrichment for science teaching. One can find a lot of educational publications and textbooks in which this aspect is encouraged. However, some caution might be necessary with several of these claims. Frequently, history is reduced to some anecdotes. They are meant to be a short recreation from the 'hard sciences'. In this respect, it is not an adequate image of the history of science that is communicated, nor is it useful with respect to educational aspects. In these anecdotes, scientists are caricatured as being either pure geniuses or completely ignorant in everyday life. Moreover, science is described as a series of marvellous discoveries, most of them made by men.[2]

In contrast to this use (which I am not advocating), history of science can also be implemented in attempting to achieve a better understanding of scientific concepts as well as of the nature of science.[3] In such an approach, historical aspects can help to develop scientific literacy as well as an understanding of science as a process —a process in which the learner possibly can participate. A specific approach in this respect is carried out at the University of Oldenburg —the implementation of historical experiments in educational situations. In doing so, our main focus is the training of physics teacher students. Yet, we have also tested modules in courses for in-service teachers as well as on school level. However, before discussing the educational aspects of this approach, let me just briefly sketch where the apparatuses and instruments we use come from.

The methodological background of the Oldenburg program

In our group, a specific focus of research lies on the analysis of experimental practice in the field of physics. In doing so, we employ what we label 'replication method'; this method can be described in three steps: The reconstruction of the apparatus, the redoing of the experiment and the contextualization of the experiences made in the first two steps. The aim of this approach is to develop an understanding of the skills, necessary requirements and difficulties that were relevant for the historical actors. In this respect, it is necessary to build and use the apparatus in the best possible agreement with the information we have collected from the sources. Thus, in order to understand the difficulties in the historical situation, it is necessary to have an apparatus (as well as to use it in a way) that corresponds to the historical one and is not just simply an 'improved' version of it.

With the experiences made during these steps, we are going back to the sources and try to find out whether these experiences had any relevance in the historical situation. It should be understood that the three steps are not separated in practice, but only for analytical rea-

2. For a criticism of such images see (Hentschel, 2003).
3. With respect to this aspect see in particular (McComas, 1998).

sons in my discussion.[4] However, whilst research with the replication method focuses entirely on the history of science, a peculiarity of the Oldenburg approach lies in an additional aspect: Quite a lot of the apparatuses are used in science teacher training (as well as in science teaching on school level).

Using historical experiments in science teacher training

Basically, there are three areas in which these experiments are used in the Oldenburg programme of science teacher training: Central is a lab course which is compulsory for all teacher students in our department. This course takes four hours a week and is accompanied by a seminar that takes another ninety minutes.[5] Apart from this, we offer seminars with practical parts on aspects of the history of physics which are voluntary and take usually two hours a week. And the students have the opportunity to prepare their final thesis on an historical experiment.[6] This means that they carry out a research project which (at least in case of experimental work) takes six months and results in a written thesis of some 100 pages.

The lab course, which is central to my discussion, is offered to students who are in their third or fourth year of training (which means that they have a substantial physics background).[7] They work in groups of two, and they work on a different experiment every week. It has to be understood that this course does not only consist of historical experiments. Instead, the students have also to deal with some of the classical school experiments; they get familiar with computer-assisted measurements that are intended to be used on school level and computer simulations.[8] Yet, there are also the historical experiments, and these are my focus in this paper.

The students get some 25 pages for their preparation; in case of the historical experiments, these 25 pages also include the description of the experiment and its historical context. As already mentioned, they spend four hours in the lab, and they are required to submit a report that does not only contain the physics background of the experiment, the data and their evaluation but also a didactical reflection of their experiences. In other words, the

4. For a detailed discussion of this method see (Heering, 1998; Sichau, 2002), for a summarizing description see (Heering, 2005).

5. For discussions of this programme or of specific aspects of this lab course, see (Rieß, 1995; Rieß, 2001; Heering, 2003), for the use of historical experiments in science education see also (Devons & Hartmann, 1970).

6. For exemplary results from such a thesis, see e.g. (Ecke & Rieß, 1995; Heering & Osewold, 2005; Nawrath, 2007).

7. In the following, I am describing the course as it was implemented in the traditional way of teacher training. Due to university policy, the organisational structure as well as the syllabus are going to be changed significantly. This change had also an impact on the courses. Yet, as we are still in the period of developing this new syllabus, it is too early to draw any conclusions. However, it has already become obvious that in the new structure, the students are not able to take any courses voluntarily. Therefore, the broadness of their study is significantly reduced.

8. These parts are not necessarily ahistorical; the students work, for example, with an astronomical simulation that can also be used in historical contexts, see (Metz *et al.*, 2003).

students are to discuss, whether they would use the experiment in their future school teaching and, if so, how they would do it and what they would attempt to achieve with their teaching. Or, if they decide that they would not use the experiment in their teaching, they are to discuss what they would use instead to teach the topic and how they would do it.

Among the historical experiments that we are using are Coulomb's law in electrostatics (which I am going to discuss in some detail), Ohm's law (see Fig. 1), 18th century electrical experiments —among them Franklin's bells, experiments with Leyden jars (see Fig. 2) and the electrical ignition of a liquid, Gauß' and Weber's determination of the magnetic field of the Earth in absolute measures, and Rumford's experiments on radiant heat (see Fig. 3). One of the experiments —which is most likely unfamiliar to most people— is Thomas Young's eriometer, and I am going to discuss this experiment also in some greater detail.

Figura 1.

Figura 2.

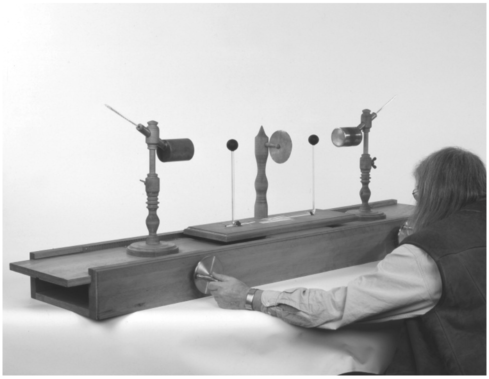

Figura 3.

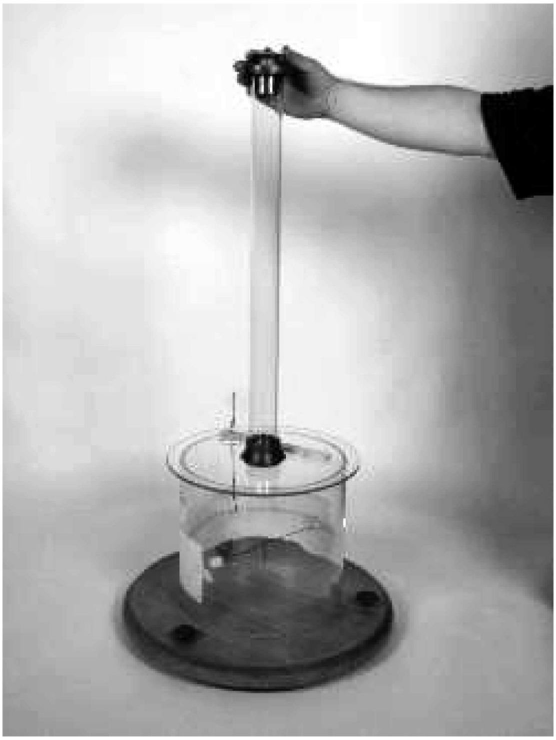
Figura 4.

Coulomb's determination of the ratio between electrical (repulsive) force between two charges and the distance between these charges is one of the canonical experiments from the history of physics. Actually one can find the diagram of Coulomb's torsion balance in many textbooks. Coulomb, a military engineer, published his paper in which he described the torsion balance and the demonstration of the force distance relation in 1785. Central to the instrument (see Fig. 4) is a very thin metal wire (some 40 m diameter), at the end is a copper cylinder fixed that carries an insulating needle. At one end of the needle, a pith ball is attached that is in contact with a second pith ball at the beginning of the experiment. Both balls are charged, they repel each other and the first ball moves away from the second, thus twisting the metal wire. This twist requires a force which is proportional to the angle of twist, at the same time the repulsion decreases with the distance, consequently there is an equilibrium situation at which the ball will finally come to rest. The angle between the balls is read, and then the torsion of the wire is increased with the help of the torsion micrometer, the ball moves closer to the other and comes to rest at a new equilibrium position.

Coulomb published the following data (and these data are also given to the students):

> «First Trial. Having electrified the two balls by means of the pin head while the index of the micrometer points to 0, the ball a of the needle is separated from the ball t by 36 degrees.
>
> Second Trial. By twisting the suspension wire through 126 degrees as shown by the pointer o of the micrometer, the two balls approached each other and stand 18 degrees apart.
>
> Third Trial. By twisting the suspension wire through 567 degrees the two balls approached to a distance of 8 degrees and a half.» (Magie, 1935: 412).

This is it —no more data, this is Coulomb's entire proof (and actually it is not a proof, but this is a different story)[9] of the inverse square law in case of electrostatic repulsion. When the students are asked to comment on these data, their first reaction is that three sets are not enough, there is no standard deviation etc.[10] However, one of the aspects they are to learn (and this is pointed out during the discussions with the students) is that Coulomb's procedure was according to the standards of the eighteenth century.

The students get to work with a reconstructed torsion balance, and they quickly start to realise that this experiment is not as simple as it sounds, but that the instrument is very sensitive —and at the same time very error-sensitive. Yet, they do not only encounter difficulties on the practical level, but also on the theoretical level when they are asked to deal with Coulomb's data: As he wrote, one can easily see from these three sets of data that the force varies precisely with the square of the distance. Surprisingly, quite a lot of the students fail in attempting to show the concordance of the data with the relation. However, it is easy to demonstrate —yet, one has to know how to look at the data. The crucial point is to look at the torsion and not at the reading of the torsion micrometer.[11]

There is another aspect that can be illustrated with the data: There is actually a slight discrepancy with respect to the third trial. Instead of 9° (as it should be), the distance is only 8.5°. This aspect has been mentioned by Coulomb who blamed charge leakage for this small deviation. This sounds very plausible to everyone who has carried out electrostatic experiments. Consequently, this small difference of 0.5° seems to be negligible. At least this is the case for most of the students who are discussing Coulomb's data, yet, as one can easily show, such a deviation is equivalent to a reduction of the micrometer angle of more than 60° —and this is no longer considered to be a small, negligible deviation.

What the students can understand from these discussions of Coulomb's data is the necessity to look at the physical meaning of data instead of just considering the numerical value. Likewise, the insights of the first part of the discussion is also a more general one, yet, one that is not based that much in epistemology but more in educational aspects: By experiencing the necessity of knowing how to look at data, the students make first hand experiences with an aspect that is highly relevant to their future teaching: students at school have not yet learned to look at data with the right perspective. Consequently, they might experience difficulties where everything looks simple and straightforward to the teacher. Making teacher students sensitive to this problem is therefore one of the aspects that are relevant with respect to this particular experiment.

9. For a detailed historical discussion of the torsion balance experiment see (Heering, 1994; Heering, 1998).

10. This reaction can be seen as an outcome of the first lab course the students have to take and in which a strong emphasis was laid on these aspects.

11. The torsion is the sum of the reading at the micrometer and the distance; for a more detailed discussion of these mathematical aspects see (Heering, 2001).

At the same time, the students experience the difference between the experimental practice with a torsion balance and the electrical experiments from the Enlightenment (which they had carried out on a previous term. Thus, in comparing these two experimental practices, the students are to realise that experimental practice is nothing stable but can undergo significant changes. As a consequence, the students are to realise that science (and scientific practice) are to be understood in terms of cultural activity that is not independent of its cultural context.

From this discussion it should have become clear that the aim in confronting the students with the historical apparatus is not only to familiarize them with historical aspects of scientific practice, but to make them develop an understanding for key aspects of the nature of science and thus become able to make these aspects also a topic in their future science classrooms.

This is also one motivation for the implementation of the second experiment from this course I would like to discuss briefly: the so-called Eriometer —the Greek word erios meaning wool, thus the instrument is a wool measurer, or, to be more accurate, it is a device to measure the diameter of small particles. This instrument, initially described by Thomas Young early in the 19th century, has never been adopted. The working principle appears fairly simple: Light falls through a hole in a plate onto a sample and into the eye of the observer. The distance between the sample and the plate can be varied. In the plate are some more holes which form a circle around the one through which the light falls directly into the eye of the observer. If the sample has a fairly similar diameter, the observer should see colourful diffraction rings —the distance is to be adjusted in a manner that the circular light points that result from the circular holes appear at a specific part of the diffraction ring— e.g. at the border between red and yellow. The distance between the sample and the plate serves as a measure of the particle diameter —if the instrument is calibrated with a sample of known diameter, absolute measures are possible.[12]

The instrument can be realized from brass, but, and this makes the device attractive in several respects, Young also described a version which consists of two pieces of cardboard, a measuring tape and some needles that are meant to hold the sample (see Fig. 5). What the students can understand from working with this device is that obviously the instrument is appropriate for the measurement of the diameter of small particles. At least this is what they realize once they have learned to see with the device, certain visual skills are to be developed in practicing with this device. Again, the students can develop insights into experimental practice, but there is another aspect that is highly relevant to the implementation of this device into the course: the eriometer was rejected in the historical situation, however, it is working. Consequently, the students can understand that technical applicability might be a

12. For a historical analysis of the eriometer see (Weber, 2001); for some discussion of its didactical potential see (Kipnis, 1993; George & Guarino, 1973).

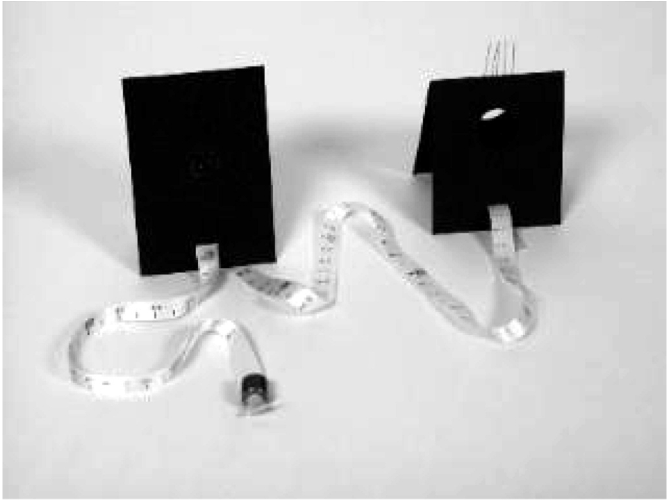

Figura 5.

relevant issue with respect to the acceptance of a scientific concept (such as diffraction), yet, it is not a sufficient criterion. On the contrary, not only the concept was not accepted but the instrument was rejected, too.

This is, of course, one of the reasons why these experiments can also be used in school. Yet, there are other aspects that are relevant from my understanding. First of all, the students are able to develop a conceptual understanding by redoing some of the experiments that were crucial for the initial development of this concept. This can be done e.g. in case of electrostatics, where students can start by classifying materials, then discuss the generation and effects of electricity produced with a frictional generator, and finally develop an understanding of the concept of electrostatic induction by using an electrophorus. Also, it is possible to use the discharge of a Leyden jar in order to introduce the concept of an electrical circuit. In using historical experiments and instruments, a major aspect is also the 'transparency' that can be attributed to the devices: The students have the impression that the behaviour of the instruments is understandable to them and that they can develop this understanding by working with the apparatus.[13] Moreover, and this is certainly not to be underestimated, the students can have fun, and this is not very common in teaching electrostatics.

I hope I have been able to show why historical experiments can be useful in science teaching and what can be achieved in implementing some of these experiments (and I would like to point out that I am not propagating an entirely historical teaching, but

13. This is in particular the case with experiments from the Enlightenment; for a more thorough discussion of this aspect see (Heering, 2007).

that history of science is used when it is considered to be an enrichment of the traditional way of teaching). Yet, I have not made clear why I think that such an approach could also be beneficial to historians of science.

Potential benefits to history of science from educational uses

At least in Germany, but probably also in other countries, a discussion has started about what kind of research is necessary and should be funded. The arguments are not purely scientific, as the discussion is basically a political one and, in this context, economic arguments play an important role. In this respect, history of science appears to be in a somewhat weak position, as it is a small field which means that there is no huge lobby speaking for it. Moreover, there is hardly any outcome from the research in history of science that can be marketed; consequently, getting funded is not that easy. Thus, it appears that standing for its own, history of science as an academic discipline can be seen as threatened by economically justified shortenings. Therefore, it appears to be necessary to show the utility of the field in a manner that goes beyond the simple statement that it is important to know how things have developed.

In this respect science education can be a strong ally, not only, because the number of people working in this field is significantly larger than in many other areas. It is also an area that politicians and the general public consider to be highly important. Moreover, due to recent multinational evaluations such as the TIMMS and the PISA study, aspects from science education have come into public focus. Thus, demonstrating that there is a necessity for history of science in science education would also mean to make clear that there is a necessity for history of science itself.

As I have attempted to show in this paper, science education can benefit from the implementation of historical experiments. This is not limited to historical experiments, on the contrary: Other approaches such as case studies, dramatisations, or multimedia approaches can also be very useful in this respect.[14] Particularly relevant appears to be that aspects such as the nature of science or epistemological beliefs can be addressed through the history of science. These aspects have become a major issue in science teaching, as has contextual teaching. In both fields, history of science is able to make significant contributions. Therefore, history of science can be an important enrichment to science education. But at the same time, history of science can benefit from such a cooperation —a cooperation that can be labelled as being symbiotic.

14. For case studies that are discussed with an educational perspective see e.g. (Allchin, 2001; McMillan, 2007; Metz, 2008); for role plays see in particular (Stinner, 2007). F. Bevilacqua is currently very active in creating materials for the internet that are using a web 2.0 approach, see http://dhstiuhps.ning.com/, last access Jan 28th, 2008; and http://dhst.wetpaint.com/, last access Jan. 28th, 2008.

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