Objects of Understanding

Historical Perspectives on Material Artefacts and Practices in Science Education

Edited by
Peter Heering and Roland Wittje

Franz Steiner Verlag



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Cover illustration:
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Bibliographic information published by the German National Library:
The German National Library lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic information is available at
dnb.d-nb.de.

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© Franz Steiner Verlag GmbH 2025
Maybachstraße 8, 70469 Stuttgart
service@steiner-verlag.de
www.steiner-verlag.de
Layout and production by Franz Steiner Verlag
Typesetting: DTP + TEXT Eva Burri, Stuttgart
Print: Beltz Grafische Betriebe, Bad Langensalza
Printed on acid-free and age-resistant paper.
Printed in Germany.
ISBN 978-3-515-13788-1 (Print)
ISBN 978-3-515-13795-9 (E-Book)
DOI 10.25162/9783515137959

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Introduction*
Objects of Understanding – Historical Perspectives on Material Artefacts and Practices in Science Education

PETER HEERING / ROLAND WITTJE

The history of science education remains an underexplored and underrepresented topic within the history of science, despite the crucial role that science education plays in the formation, stabilisation, dissemination, movement and transformation of scientific knowledge and scientific practises. This is true even more so for the material cultures and practices of science teaching. A broad variety of material practices that were labelled as demonstrations or experiments by teachers and students, model making, object handling, dissection, image projection and showcasing objects have been central to science education throughout its history. Extensive teaching collections, teaching infrastructure, and the built environment at schools, colleges and universities bear witness to the importance of these cultures and practices, which largely remain unstudied by historians of science (Wittje, 2023).

Some 13 years ago, we were writing the introduction to *Learning by Doing: Experiments and Instruments in the History of Science Teaching* (Heering & Wittje, 2011). In some respects, this current edited volume can be seen as a continuation, yet also an expansion of *Learning by Doing*. Together with the authors of this volume, we no longer only look at instruments and demonstrations, but also address other material objects, collections and practices that have been used in educational processes. The last couple of decades have witnessed a rapidly growing interest in university collections es-

* We thank the Zentrum für Bildungs-, Unterrichts-, Schul- und Sozialisationsforschung (ZeBUSS) at the Europa-Universität Flensburg for financially supporting both the participation of early career scholars in the initial conference and in particular the publication of this volume. We also thank the DFG for supporting the initial conference and thank the Cultural History Museum of the University of Oslo for supporting the publication of this volume.

pecially in Europe, most of them related to teaching, which aim to preserve the rich material heritage of universities (Soubiran et al., 2009). Studies of school collections, in contrast, remain sporadic.[1] A substantial number of these studies address teaching collections, but not the teaching with the objects that form the collection (Bernard, 2018; Canard et al., 2022; Malpeli, 2021). However, some works have appeared in recent years that deal with the history of instruments and experiments within the practice of science education (Bertozzi, 2021; Heering, 2023; Markert, 2022; Markert, 2024; Vaupel & Preiß, 2022).

While we have to conclude that the research field of the history of material cultures of science education has not changed much since 2011, this volume once again brings together histories and case studies from the 18th century to our contemporary times, which, taken together, demonstrate the potential of the field. The studies have become more global: In addition to a series of case studies based in Europe or North America, Roland Wittje investigates the attempt to implement German methods of physics education in India at IIT Madras, and Maria Gabriela Mayoni discusses the establishment of objects, collections and practices for teaching natural history in Argentina. Panagiotis Lazos presents a case in which a scholar from the Greek periphery develops a teaching device that made it into the European centres. Together, these studies address how teaching objects, collections and practices travel, what might obstruct their travel, and how they are shaped and transformed within a local environment and social context. As Mayoni concludes, 'local and foreign materials coexisted. …. A dialogue between a type of 'universal science' … with local nature … was formed in the classroom'.

Infrastructures and built environments are a recurring topic in several papers. Jamilla Notebaard and Dulce da Rocha Gonçalves discuss the use of magic lanterns as omnipresent teaching devices in the early 20th century Netherlands. In doing so, they highlight the creation of the respective architecture and infrastructure, such as J.W. Moll's lecture hall in Groningen, which was designed in a special manner that made it particularly suitable for lantern projections. Environmental aspects play a key role in Wittje's contribution as well – here however in a significantly different manner: Wittje demonstrates how the climate and architectural environment in Madras presented a challenge for the transfer of the Robert Pohl's system of lecture demonstrations established in Göttingen. The built environment of teaching devices is also a main concern of Jean Davoigneau, Delphine Issenmann and Loïc Jeanson, who discuss the integration of both research and teaching at the Strasbourg observatory, which distinguished it from other French and German observatories. Together, these studies demonstrate that teaching instruments, collections and practices need to be studied within their built environments, environmental conditions, and within scientific infrastructures.

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1 See Rivera Colomer, 2024; Simon et al., 2009; and Talas, 2010 and 2012 as examples for studies of scientific instrument collections in schools.

Three contributions come from the early 18th century and address, as Sofia Talas put it, the 'beginnings of experimental physics teaching'. Talas discusses Giovanni Poleni and his attempts to establish an experimental program at the University of Padova. One of the references for Poleni was the teaching in Leiden – Leiden as a reference place for early experimental physics teaching reappears in the contributions by Jip van Besouw and Peter Beck on the one hand, and Peter Heering on the other. The former focus in their study of teaching hydrostatics in particular on the relation between mathematical demonstrations and the teaching with instruments. The latter addresses 's Gravesande's practice with the hydrostatic balance; in doing so, he particularly discusses performative aspects of the practice with the instrument.

Van Besouw and Beck, Heering, and Davoigneau et al. all deal with the relationship between teaching and research instruments, though in different ways. Van Besouw and Beck argue that van Musschenbroek's and 's Gravesande's fountains cannot be reduced to pedagogical devices to teach students with little or no mathematical skills, as these were important instruments in the investigation of fluid flow. Heering studies the differences in 's Gravesande's hydrostatic balance in its modification as a demonstration instrument, and Davoigneau et al. discuss the transformation of a meridian circle from a research instrument into a teaching device.

Whilst these three papers address the work of academics at universities, other papers discuss school teaching and individuals who are less known to historians of science. Rosanna Evans presents her research on school practitioners developing and building their own teaching devices. In doing so, she shows which strategies teachers employed to enable themselves to enrich their classes by tailoring apparatuses to their teaching. Stephen Johnston introduces the schoolteacher Thomas E. Dexter, "not a well-known figure in the history of either science or education". Dexter developed and marketed the Portable Museum, which were educational boxes to teach object lessons to children in both formal and non-formal settings.

An important aspect discussed in Johnston's paper is the marketplace for teaching objects and collections, which is a recurring topic in several papers. While Dexter's Portable Museum introduced raw materials and trade products from different parts of the empire, it was itself a trade product, manufactured and sold over an extended period. Jörg Zaun and Kirsten Vincenz discuss the object tableau as a different type of educational box, which displays raw materials or finished products. Most case studies address objects that required or at least enabled a manipulative interaction either between the learner or with the teacher and the object. This is not the case with the kind of educational boxes that Zaun and Vincenz introduce: in the object tableau, the objects are not meant to be removed but to be studied in their didactic arrangement through the covering glass. In a naïve perspective, one may argue that these object tableaus speak for themselves, yet, as Zaun and Vincent demonstrate, this is not the case.

In an ethnographic approach, Jochen Lange describes the processes involved in the current design of teaching instruments at a major company in the field. In doing so,

he approaches the process of developing new teaching objects as materials that facilitate science learning, and as commercial products. Richard Kremer discusses how electronics was introduced in science teaching, highlighting the importance of experimental kits for teenagers to build their own electronic devices, and modular boxes to demonstrate radio circuits sold by the instrument company Leybold. With Kristen Halverson's paper, the marketplace moves away from school science and undergraduate science teaching, to instructing practicing medical professionals. In her study of the promotion of certain medical instruments in Swedish and Danish medical journals, Halverson shows that in order to establish certain instruments as standard devices, educating professionals remotely through journal articles had to be done differently in both countries.

David Munns takes us to teaching reactors at American Universities during the Cold War. Just as these reactors were needed to train a growing number of nuclear engineers, they needed to navigate the politics of atomic energy and nuclear safety, and the expectations and promises of the Atomic Age. Along with Johnson's and Wittje's contributions, Munns' paper highlights the political, social and cultural context of the materiality of science education in which it operates, and from which it cannot separate.

While this edited volume is not a coherent presentation, nor an exhaustive or even conclusive treatment of material cultures of science education, the different chapter clearly illustrate why historians of science need to engage with the topic. If historians of science have dealt with the history of science education at all, they mainly focused on the role of science education for the formation and reproduction of scientific communities (Mody & Kaiser, 2007). However, we have to acknowledge that most science teaching has taken place outside of academic institutions. It appears to be a necessity that we do not speak of science education in general terms, but that we analyze it in a more differentiated way: At one end of the scale is the non-formal education of young people and general school education, both of which arise from socio-political concepts and have a function in the creation of useful members of society. At the other end is the qualification of scientific researchers who are to become members of the relevant collective and thus receive a very specific introduction to the subject in question and the culture established in it (perhaps only locally). In between are, for example, technical training courses that qualify students for certain professions outside of research, but also degree courses that aim to qualify students for a corresponding profession (such as practicing doctors or pharmacists).

The relationship between science and the public has become a major theme within history of science in recent decades. Somehow, formal science education in schools, colleges and technical training has, by and large, not been part of this endeavour, which is surprising give the crucial role that formal education plays in the coproduction of science and society. We need to add, of course, that a number of historians of science have written about the relationship between formal science education in schools and

the formation of society (see, for example, Roberts, 2012; Kohlsted, 2010; Nyhart, 2009; Olesko, 1989).

When discussing educational processes in the natural science disciplines, it seems necessary to consider the differentiation called for above. How did the reproduction of researchers in the natural sciences take place? What demands have been placed on scientific training by practitioners (including at university level), by whom and with what demands? And finally, how was science education conceived in the context of a general education, what role was ascribed to it and what demands were associated with it? The question is not only what was taught, but also what was learned. And here it is less important to ask what content was learned, but rather what understanding of nature, of science and of one's own role in the world was achieved through the respective educational processes. We have to address these and other questions as historians of science if we claim to take science educations seriously. For this, we need to study not only science textbooks, but also teaching devices and teaching collections, which became central to the practice and epistemology of science and its pedagogy in the early 18th century, and remained so until this day.

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At the Beginnings of Experimental Physics Teaching

SOFIA TALAS

Introduction

The experimental natural philosophy that emerged in the course of the seventeenth century was mainly practiced within academies and learned societies, where observations and experiments about various aspects of the natural world were regularly carried out, attended by the academies' members. Only in a few universities, some lectures illustrated by demonstrations were proposed at the end of the century, like for instance in Paris or Leyden. At the University of Paris, Pierre Polinière actually held a series of lectures based on experiments within a philosophy course, describing his demonstrations in the book *Experiences de Physique* (Polinière, 1709). In Leyden, Burchard de Volder introduced experiments in his natural philosophy lectures from 1675 – a *Theatrum Physicum* was purposely built to host these new lectures at the end of 1675 (de Clercq, 1997; Strazzoni, 2019; Wiesenfeldt, 2002). De Volder was mainly interested in pneumatical and hydrostatical experiments, and so was Wolferd Senguerd, who started teaching natural philosophy in Leyden a few years later. Senguerd was allowed to hold his lectures in the *Theatrum Physicum* from 1705, but he found the instruments left by de Volder neglected and damaged (Wiesenfeldt, 2002; Molhuysen, 1913–1924).[1] There was actually no continuity in the use of instruments in teaching at the time: experiment-based lectures were isolated cases.

However, the situation was about to change very rapidly in a few years: from the early eighteenth century, new experimental lectures, which were to be called "experimental philosophy" or "experimental physics" lectures, started spreading from Eng-

1 My warmest thanks to Steffen Ducheyne for sharing with me his manuscript chapter on Hermann Boerhaave, which provided me with many valuable details about de Volder and Senguerd.

land throughout Europe. Their diffusion was rapid and can be seen as a "flood of Anglo-Dutch Newtonianism", as John Heilbron called it (Heilbron, 1979, p. 141). John Keill and William Whiston, both Newton's pupils, introduced these new lectures in Cambridge and Oxford universities, and the new lectures were also offered in London to a wide public. The connection with the Royal Society, chaired by Newton from 1703, was tight. The lectures widely drew on what had been performed during previous meetings of the Royal Society, and most of the lecturers were or became Fellows of the Royal Society (Morton & Wess, 1993), like for instance John Theophilus Desaguliers, who contributed significantly to the success of the new lecture-demonstrations (Soares, 2016). Desaguliers, after replacing Keill at the University of Oxford, moved to London, where he gave public experimental philosophy lectures from 1713. He travelled a lot in England and abroad, and presented his lectures in his book *A course of experimental philosophy.* Translated into many different languages, this treatise remained very popular during the whole eighteenth century (Desaguliers, 1734–44).

Two Dutchmen, Willem Jacob 's Gravesande and Pieter van Musschenbroek, both strenuous supporters of Newtonianism, then played a central role in spreading the new experimental philosophy lectures on the Continent (de Clercq, 1997). They gave lecture-demonstrations at the universities of Leyden and Utrecht, going beyond the English models they had experienced in London: they not only widened the topics covered, but also introduced new experiments and teaching devices. The treatises they published about their courses enjoyed a huge success and were translated into various languages ('s Gravesande, 1720–21, 1725, 1742; Musschenbroek, 1734, 1739, 1751, 1762). Their lectures attracted students from all over Europe, such as Jean-Antoine Nollet, known as *l'Abbé Nollet*, who was to become one of the main supporters of the new way of teaching (Heilbron, 1975). Nollet's textbooks also became very popular (Nollet, 1738, 1743–1764, 1770).

The lively activities carried out by Nollet and the Dutch and English experimental philosophy pioneers brought forth striking results: the new lecture-demonstrations reached the whole Europe and the British colonies in North America within a few decades. Chairs of experimental philosophy were created in many universities and cabinets of physics, homogeneous collections of scientific instruments, were set up mainly for teaching purposes though some instruments, like electrostatic generators for instance, were also used for research activities.

Though Newtonian lecture-demonstrations certainly dominated the scene, other lecturers, not related to the Anglo-Dutch stream, also included experiments in their teaching in those years. In Germany, in particular, the experimental lectures given in Altdorf by Johann Christoph Sturm at his *Collegium Curiosum* from 1672 (Sturm, 1676) influenced several university professors, like Christian Wolff, who taught in Halle from 1706 and in Marburg from 1723. Wolff's Cartesian experimental way of teaching spread to several universities: it arrived in Kiel, in Leipzig and in Uppsala (Heilbron, 1979). Nonetheless, it should be noted that Wolff's successors also included in their lec-

tures elements of the Anglo-Dutch experimental lectures. The various models of lecture-demonstrations introduced in those years actually merged quite quickly, and the case of the University of Padua is paradigmatic in this sense. The chair of experimental philosophy, created there in 1738, was assigned in February 1739 to Giovanni Poleni, who was regarded as an expert of experimental natural philosophy (Talas, 2013; Del Negro, 2013; Salandin & Talas, 2000; Grandjean de Fouchy, 1763).[2] To set up his new lectures, Poleni followed the Anglo-Dutch pattern: he proposed many experiments designed by Desaguliers, 's Gravesande and Musschenbroek, and he entitled the manuscript notes of his lectures *Physices elementa mathematica experimentis confirmata,* just like 's Gravesande's well-known treatise. Furthermore, in his letters, Poleni often enthusiastically mentioned "Musschenbroek, so well-known in the art of experimenting",[3] or the "skilfull experimental philosophers, P. Musschenbroek and Guglielmo Giacomo 's Gravesande".[4] However, Poleni also mentions "Christian Wolff in Germany", together with "Desaguliers in England and in Holland Musschenbroeck and s' Gravesand" who all, according to him, "perform experiments as an Art".[5] An instrument acquired by Poleni to study the refraction index of liquids is particularly relevant to show how the Newtonian and Wolffian experimental teaching merged (Fig. 1), designed by Wolff,



Fig. 1 Instrument to study the refraction index of liquids. Designed by Christian Wolff, it was made for Giovanni Poleni by Philippe Vayringe in the early 1740s. The liquid to be studied was put in the prism container (on the right in the photograph). The light entering through the lateral hole was deviated as it passed through the liquid, and the mobile arm was then moved until the refracted ray of light hit the square wooden piece at the extremity of the arm. Giovanni Poleni Museum, University of Padua.

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2 Poleni taught at the University of Padua from 1710, holding at first the chair of "Astronomy and Meteors". He then started teaching natural philosophy in 1715 and was assigned the chair of mathematics in 1719.

3 "Il Musschenbroek, si celebre nell'arte di esperimentare". Poleni, G., letter to Zendrini, 12 febbraio 1739: BMVe, Cod. It. IV, 643 (=5504), c. 19–20.

4 "valentissimi filosofi sperimentali, P. Musschenbroek e Guglielmo Giacomo 's Gravesande". Poleni, G., letter to the Venetian *Riformatori*, may 1761: BMVe, Cod. It., X, 313, c. 78.

5 "li signori Cristiano Wolfio in Germania, Desaguiliers in Inghilterra et in Ollanda Mussembroeck e s'Gravesand. Questi degli esperimenti fanno un'arte". Poleni, G., letter to Morosini, s. d.: BMVe, Cod. It., IV, 592 (= 5555), c. 191.

the device was made by Philippe Vayringe, an instrument-maker and lecture-demonstrator at the Court of Lorraine, who had spent time in England to learn from Desaguliers about the new teaching experiments and instruments (Talas, 2012 and 2013).

In the last decades, some studies have examined eighteenth-century lecture-demonstrations and cabinets of physics (de Clercq, 1997; Morton & Wess, 1993; Bennett & Talas, 2013), but many aspects still need to be further analyzed, such as the processes of diffusion of the new lectures, their shared features and local peculiarities, and the national and international networks that linked scientists to one another. A complete and detailed analysis on a European scale goes beyond the scope of this paper. The present work is based on the study of the first main experimental philosophy treatises and cabinets, as well as on letters and manuscripts related to Giovanni Poleni, who can be regarded as a paradigmatic first-generation lecture-demonstrator. After examining the main features of the new lecture-demonstrations, the paper will discuss their audiences and focus on the challenges the first professors of experimental philosophy had to face, such as finding a balance between mathematics and experiments, setting up structured and meaningful courses, and developing teaching methodologies that took into account students' needs. We will also see the specific skills professors were expected to have, as they were supposed to design new experiments and instruments and to know how to choose, use, handle, preserve and repair scientific instruments. The paper will finally examine the impact of 18th-century experimental philosophy lectures, underlining how they contributed to the birth of physics in a modern sense and to shaping physics teaching up to the 19th and 20th century. We will also see how the new lectures strongly enhanced science popularization and contributed to bring forth new generations of physicists from the early 19th century.

Main features and audience of the new lectures: science becomes public

One of the aims of the new experimental philosophy lectures was to provide direct and immediate demonstrations of Newton's philosophy, as 's Gravesande wrote to Newton in 1718:

> I begin to hope that the way of philosophizing that one finds in this book [Newton's *Opticks*] will be more and more followed in this country, at least I flatter myself that I have had some success in giving a taste of your philosophy in this university. As I talk to people who have made very little progress in mathematics I have been obliged to have several machines constructed to convey the force of propositions whose demonstrations they had not understood. By experiment I give a direct proof of the nature of compounded motions, oblique collisions, and the effect of oblique forces and the principal propositions respecting central forces (de Clercq, 1997, p. 76).

For example, in order to demonstrate that projectiles follow a parabolic trajectory – as Galilei had discovered in the previous century – 's Gravesande invented a device, in which a small sphere was released along a track, thus acquiring a horizontal velocity at the end of it. A parabola with its coordinates was drawn on an adjacent vertical panel and a few rings were fixed along the parabola. The small sphere passed through all the rings, thus showing that the motion of a projectile is a parabola. This instrument, as well as many others designed by the Dutch scholar, became a classic element of eighteenth-century cabinets of physics (on this device see also Van Besouw & Beck in this volume).

The new lectures were supposed not only to provide clear experimental demonstrations, but also "to combine pleasure and usefulness",[6] as Nollet wrote in 1738 (Nollet, 1738, p. xi). The point was to maintain a good balance between the seriousness of the course and the spectacular features of the proposed experiments. The so-called 'mechanical paradoxes', mentioned in most treatises of the time, are emblematic of this approach. The double cone, for instance, which appeared to roll upwards, surprised and struck the audience, defying expectations. Then the lecturers showed that its center of mass was actually moving downwards, and the experiment could thus open the way to a reflection on the laws of mechanics. A lecture could also start with Tantalus vases, made of glass, in which a fluid was poured. It seemed possible to fill the vases normally at first but, when they were almost full, the fluid started pouring out from the spouts located underneath. Why? Lecture-demonstrators explained that this was due to the siphon fixed at the center of the vases and thus discussed in more details the way siphons work and the action of atmospheric pressure. As Nollet emphasized in 1770:

> Think that though you are allowed to catch the attention of your audience through phenomena that surprise them, letting them ignore the causes, when these can be known, does not fit the dignity of a physicist. So, though glass is fragile, it is necessary to introduce it in the construction of Physics machines, preferring it to metal or to other opaque materials, whenever transparency could help us to see the mechanism of processes, because, as I already said, our first aim must be to teach, enlighten, and not to surprise or embarrass (Nollet, 1770, p. xxi).[7]

The public essence of science in the Age of Enlightenment emerges from these words.

Being so spectacular, the new experimental philosophy lectures rapidly enjoyed a huge success not only in universities, but also in *salons* and royal courts as well. Science

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6 "joindre l'agréable à l'utile" (Nollet, 1738).

7 "Songez que s'il vous est permis de fixer l'attention de vos Auditeurs par des phénomènes qui les surprennent, il n'est pas de la dignité d'un Physicien de leur laisser ignorer les causes, quand il peut les leur faire connoître; ainsi, quoique le verre soit fragile, il faut le faire entrer dans la construction des machines de Physique préférablement au métal & aux autres matières opaques, toutes les fois qu'on pourra s'aider de sa transparence pour faire voir le méchanisme des opérations: car je le répète, notre premier point de vue doit être d'enseigner, d'éclairer, & non de surprendre ou d'embarrasser" (Nollet, 1770).

turned from private to public. Voltaire's enthusiasm is paradigmatic of this turn. A passionate supporter of Newton, he started writing in 1735 a treatise that was published in 1738 with the title *Eléments de la philosophie de Newton* (Voltaire, 1738). In December 1736, he was forced to go into exile in the Netherlands for several months and there he met 's Gravesande and the Musschenbroek brothers, Pieter and his brother Jan, a renowned instrument-maker (Voltaire, 1837). Back to France, Voltaire decided to acquire instruments for experiments and demonstrations. He bought most of them from Nollet, spending a great amount of money, so that he wrote in October 1738: "the *Abbé* Nollet is ruining me" (Voltaire, 1837, p. 290).[8] He specified on another occasion that "we are living in a century, in which you cannot be a scientist without money" (Voltaire, 1837, p. 269).[9] The philosopher approached experimental philosophy very seriously and was afraid that, in the *salons*, it would be just a passing trend, as he wrote in 1735: "Verses are not fashionable in Paris any longer. Everyone starts being a geometer or a physicist. People are interested in thinking. [...] I do not regret that [experimental] philosophy is being studied, but I do not want it to become a tyrant excluding everything else. Here in France, it is just a trend that succeeds others and will vanish as well. But no art, no science should be fashionable" (Voltaire, 1837, p. 154).[10]

We must say that experimental philosophy demonstrators, who were sometimes also instrument-makers, often contributed to the success of their lectures by paying much attention to what we could call "marketing aspects". For example, some of them published syllabuses of their courses, providing the list of experiments they proposed together with the related devices. Desaguliers even published a bilingual syllabus of his course in English and in French (Desaguliers, c. 1723), and so did Philippe Vayringe, whose syllabus was bilingual in French and Italian, as he aimed at promoting his lectures and instruments within and outside the Lorraine Court, after he moved from Lunéville to Florence, in 1737 (Talas, 2012; Vayringe, 1739).

Experimental philosophy lecturers not only made science become public, but many of them also widened their audience by including women in their lectures. Nollet, for instance, explained in 1738 that "People no longer think that knowing something that could be definitely ignored should be a reason to flush; it is well known that an enlightened spirit is not incompatible with other attractions" (Nollet, 1738, pp. xxviii–xxix).[11]

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8 "l'abbé Nollet me ruine" (Voltaire, letter to Thieriot, 27 October 1738, in Voltaire, 1837).

9 "nous sommes dans un siècle, où on ne peut être savant sans argent" (Voltaire, letter to Moussinot, June 1738, in Voltaire, 1837).

10 "Les vers ne sont plus guère à la mode à Paris. Tout le monde commence à faire le géomètre et le physicien. On se mêle de raisonner. [...] Ce n'est pas que je sois fâché que la philosophie [expérimentale] soit cultivée, mais je ne voudrais pas qu'elle devînt un tyran qui exclût tout le reste. Elle n'est en France qu'une mode qui succède à d'autres et qui passera à son tour. Mais aucun art, aucune science ne doit être de mode" (Voltaire, letter to Cideville, 16 April 1735, in Voltaire, 1837).

11 "On ne croit plus qu'il y ait à rougir de sçavoir ce qu'on pourroit absolument ignorer; on sçait qu'un esprit éclairé n'est point incompatible avec d'autres agrémens" (Nollet, 1738).

Women attending lectures or performing experiments were actually widely represented in various experimental philosophy treatises of the time (Fig. 2). Nollet also wanted to include children because, as he underlined, "Having seen as a recreational form the first principles demonstrated in a way that aroused his curiosity, a child will get by himself closer to the applications with just a little help, and when it will be time to engage him more seriously in the study of physics, his spirit, having been predisposed for a long time, will devote itself to the task with less fatigue and more success" (Nollet, 1738, pp. xxxii–xxxiii).[12] Just like women, many kids are depicted while they carry out experiments in the plates of eighteenth-century experimental philosophy textbooks.

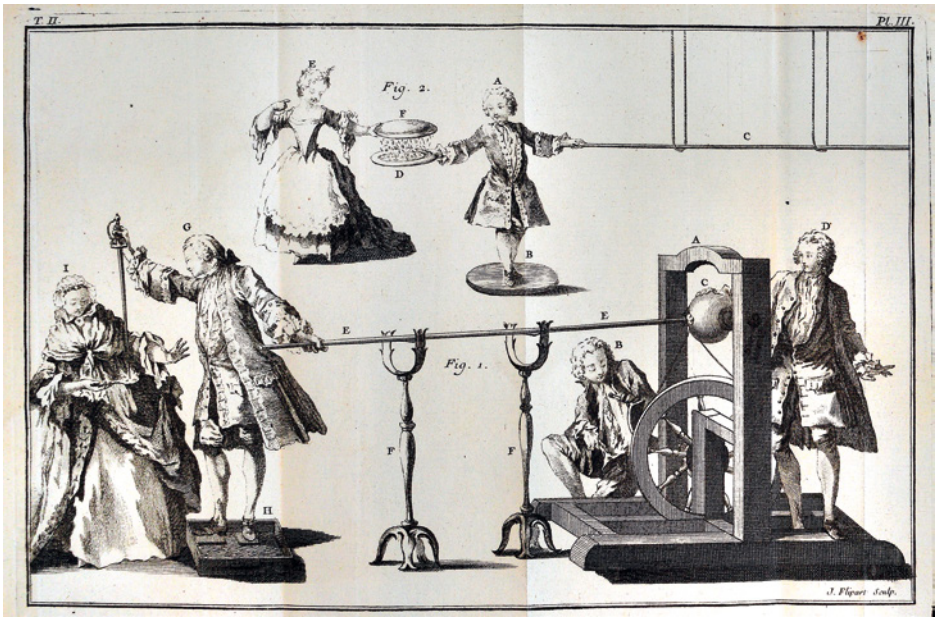


Fig. 2 Experiments on electrostatics involving women and kids. The woman on the left has a spoon filled with alcohol, so that the sparks that occurred between the sword and the spoon set the alcohol on fire. The two kids in the upper part of the illustration each hold a plate: elder pith balls are attracted and repelled by the plates, moving very quickly between the two plates (Watson, 1748).

12 "Un Enfant qui aura vû par forme de récréation les premiers principes démontrés d'une maniere capable d'intéresser sa curiosité, se portera de lui-même aux applications pour le peu qu'il soit aidé, & quand il sera tems de l'appliquer plus sérieusement à l'étude de la Physique, son esprit disposé de loin s'y livrera avec moins de peine, & plus de succès" (Nollet, 1738).

The mathematical issue

With such a diverse audience, one of the main challenges the first lecture-demonstrators had to face was related to the use of mathematics. According to Nollet, physics should "become a common good owned by everyone" (Nollet, 1738, pp. vi–vii),[13] but it "appears only [...] with geometrical characters and fraught with Algebra" (Nollet, 1738, p. xxxiii).[14] Nollet thus decided to radically eliminate any mathematical formula from his lectures.

However, not all experimental philosophy lecturers fully agreed on this issue and Poleni, for instance, discussed in 1761 the "great difficulty in practising Experimental Philosophy. Practising it (as an example) as some do, at home, with the participation also of women, to whom nothing difficult has to be presented, with the doors closed, with a certain number of machines and using his own native tongue, is one thing. But it is much more difficult and heavy to practise Experimental Philosophy to its full extent: with dignity, knowledge, and also for those who have already studied and already know about Physics and Mathematics".[15]

How much and what mathematics to include was an issue examined and discussed by most of the first lecture-demonstrators. The point was to find a balance between mathematics and experiments. Desaguliers wrote for instance in the Preface to *A course of Experimental Philosophy* that "As the greatest Part of my Auditors, at whose Desire I have printed this Course, are but little vers'd in Mathematical Sciences; the Lectures are free from difficult geometrical Demonstrations and algebraical Calculations; and the same thing is often prov'd by several Experiments; that where one does not immediately strike with a clear Conviction, another may" (Desaguliers, 1734–1744, vol.1, *Preface*, p. 7). However, Desaguliers added a section called "Annotations" at the end of each of his chapters, specifying that "I hope the rigid Philosophers will forgive me, when they find the same Things geometrically demonstrated in the Annotations; in the perusal of which, the Mathematicians perhaps will not think their Time wholly lost. However, I don't mean to exclude common Readers from the Notes; for those that have carefully read and understood the Lectures, will thereby be qualified for comprehending what is in the Annotations" (Desaguliers, 1734–44, vol.1, *Preface*, p. 7). 's Gravesande did the same from the second edition of his *Physices elementa mathematica,* published in 1725.

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13 "devînt un bien dont la possession fût commune à tout le monde" (Nollet, 1738).

14 "se présente [...] qu'avec des caractères géométriques & toute hérissée d'Algèbre" (Nollet, 1738).

15 "grave difficoltà dell'esercitare la Sperimentale Filosofia. Il farla (per cagion d'esempio), come alcuni nella sua casa privata coll'intervento anche di donne, cui niente di difficile deve essere presentato, a porte chiuse, con un certo numero di macchine ed adoperando la sua nativa lingua, è un fatto. Ma un fatto di gran lunga più gravoso e difficile si è l'esercitar la Sperimentale Filosofia secondo tutta la sua estesa: con dignità, con dottrina ed a portata anche di quelli, che hanno già studiato per rendersi intelligenti di Fisica e di Matematica". Poleni, G., letter to the *Riformatori*, May 1761: BMVe, ms. it., X, 313, c. 78.

As Desaguliers pointed out, "to return to the Newtonian Philosophy; tho' its Truth is supported by Mathematicks, yet its Physical Discoveries may be communicated without", and "since Machines have been contriv'd to explain and prove experimentally what Sir Isaac Newton has demonstrated mathematically, and several of his own Experiments are shewn in publick Courses; a great many Persons get a considerable Knowledge of Natural Philosophy by Way of Amusement; and some are so well pleas'd with what they learn that Way, as to be induc'd to study Mathematicks, by which they at last become eminent Philosophers" (Desaguliers, 1734–44, vol. 1, *Preface*, pp. 4–5).

Nollet himself, though he did not include mathematics in his books, underlined that "a language that one absolutely has to learn is the language of Algebra and Geometry; these two sciences have fortunately been introduced into Physics; wherever they can be applied, they introduce the accuracy and precision that are theirs, they shed light and make the mind reason correctly" (Nollet, 1752, p. lviii).[16] He added that "it is not that I do not esteem, as one should, these modes of expression, which are more precise, shorter, & make it possible to follow further a large part of the knowledge provided in my lessons; I even use them very usefully when I work with people who want to make a more serious study of Physics" (Nollet, 1743, pp. xvii–xviii).[17] However, Nollet excluded mathematics from his textbooks in order not to embarrass the largest part of his readers. His intent was to publish the mathematical aspects of his lectures in specific separate volumes, though he eventually did not do so.

Radically new courses – the care for pedagogical issues

The mathematical content of the new lectures was not the only worrying issue for the first experimental philosophy professors. In February 1739, as soon as Poleni was assigned the newly created chair of experimental philosophy in Padua, he wrote to his friend, Scipione Maffei, a prominent figure of Enlightenment, that "Old as I am, and with these health problems […] I did not feel strong enough to accept such a burden […] I shall say as the English say, let's see".[18] He specified that "I will carry out experiments once a week, even in Leiden they don't do more, but I don't know how I

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16 "une langue qu'il est indispensable d'apprendre, c'est celle de l'Algebre & de la Géométrie; ces deux sciences se sont heureusement introduites dans la Physique; par-tout où elles peuvent s'appliquer, elles y portent l'exactitude & la précision qui leur sont propres, elles répandent la lumière dans l'esprit, elles le font raisonner juste" (Nollet, 1752).

17 "Ce n'est pas que je n'estime, comme on le doit, ces façons de s'exprimer qui sont certainement plus précises, plus abrégées, & qui mettent en état de suivre plus loin une grande partie des connaissances qui sont l'objet de mes Leçons; je m'en sers même fort utilement, lorsque je travaille en particulier avec des personnes qui veulent faire une étude plus sérieuse de la Physique" (Nollet, 1743).

18 "Io veramente in questa età, e con questi acciacchi […] non mi sentiva in istato di assumere questo peso […] Dirò come dicono gli Inglesi, vedremo". Poleni, G., letter to Maffei, 23 February 1739: BMVe, ms. it., X, c. 94.

will succeed: may God help me".[19] Poleni's worries should not be surprising. Only very few treatises had been published up to that moment, and Poleni was part of the first generation of experimental philosophy professors: like his colleagues, he had to set up courses that were new and quite challenging.

To examine this point in more details, let us underline that Poleni mentioned in his correspondence on several occasions "the art of experimenting" and the fact that some lecturers performed "experiments as an Art".[20] He also wrote that "it is difficult to set up a system, because a lot was written about many experiments, and extensively, but not so much about the art of experimenting".[21] What did he mean by the "art of experimenting"? Nollet wrote that he never pretended to make his lessons "a spectacle of pure entertainment, in which a large number of experiments, capable only of occupying the eyes, were repeated without design or choice" (Nollet, 1743, p. xxix),[22] and he pointed out that "both by opening my School to the public, and by offering my written lessons, my intention has always been to provide a course of experimental Physics, and not a course of experiments" (Nollet, 1743, pp. xxx–xxxi).[23] It was thus crucial for these first lecturers not to present a simple series of experiments disconnected one from the other, but to set up a "course of experimental philosophy": this was what the "art of experimenting" was about. According to Desaguliers, students and readers of eighteenth-century treatises should "begin the first Lecture, and go on regularly", so that "they may advance from the easiest Truths to those more complex ones, which are deduc'd from them; for otherwise many things may seem difficult to a Person, who should open the Book at random" (Desaguliers, 1734–1744, vol.1, *Preface*, p. 7). Nollet underlined the same concept: the various parts of knowledge "must be linked together like the parts of a building; the first serve as a foundation to establish others on which we continue to build". (Nollet, 1752, p. liii).[24] The point was thus to set up structured and meaningful courses and to provide knowledge from basic notions to more and more complex ones.

This was far from easy and, according to Poleni, to seriously perform the art of experimenting, one needed "to know as much as possible the History of all the Experiments, which have been made, the methods, contrivances, and Machines used. Moreover, the

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19 "Io farò gli esperimenti una volta per settimana, di più non facendosi nemmeno a Leiden, ma non so come riuscirò: il Signore Iddio la mandi buona". Poleni, G., letter to Maffei, 7 February 1739: BMVe, ms.it, X, 324.

20 See notes 3, 4 and 5.

21 "E' difficile piantare un sistema, perché è stato scritto di assaissimi Esperimenti, e diffusamente, non così dell'arte di esperimentare". Poleni, G., undated manuscript: BNVe, It, IV, 592 (= 5555), f° 128–130.

22 "un spectacle de pur amusement, où l'on vit répéter, sans dessein & sans choix, un grand nombre d'expériences, capables seulement d'occuper les yeux" (Nollet, 1743).

23 "soit en ouvrant mon Ecole au Public, soit en lui offrant mes Leçons écrites, mon intention a toujours été qu'il y trouvât un cours de Physique expérimentale, & non pas un cours d'expériences" (Nollet, 1743).

24 "Ces connaissances doivent etre liées entr'elles comme les parties d'un édifice; les premières servent de fondement pour en établir d'autres sur lesquelles on continue de bâtir" (Nollet. 1752).

success of the Experiments themselves, and their consequences for Natural Philosophy, or for Mathematics. This is a *Mare Magnum*, which depends on a great number of Books, and on long reading and application".[25] As for the structure of the new courses, Poleni wrote that these could be ordered according to what was easier for the lecturer, or "according to the divisions introduced by the philosophers",[26] i. e. according to the four elements – earth, air, water and fire –, or "according to the order of natural and mathematical things".[27] He explained that the last structure consisted in starting with the experiments related to statics, then continuing with "the Experiments on Hydrostatics, those related to the Mechanics of Machines, the Experiments on Optics, the Experiments on Vacuum, and so on".[28] Poleni concluded that "this would be the best order".[29] We actually find this kind of structure in the main experimental philosophy treatises of the time, which were usually divided in sections that corresponded to or could be grouped according to some or all of the following main topics: properties of bodies, various aspects of mechanics, hydrostatics, hydraulics, pneumatics, heat (called "fire" at the time), light, sound, astronomy, magnetism and electricity. Machines in which theoretical knowledge was applied were also described, often in dedicated sections, showing the interest of experimental philosophers for practical issues – models of such machines were part of most 18th-century cabinets of physics. Except for the first section of most treatises, which focused on the properties of bodies, the order of the topics varied from one author to another. Furthermore, while the first treatises, like Desaguliers' *Course of experimental philosophy,* included only some of the topics (Desaguliers, 1734–1744),[30] the later textbooks, like Nollet's *Leçons de physique expérimentale,* presented all subjects with a systematic approach (Nollet, 1743–1764). Quite interestingly, the place of electricity varied quite a lot in the various experimental philosophy treatises. After briefly presenting it in the chapter about the properties of bodies, Desaguliers inserted two previously published dissertations related to electricity within a chapter about pneumatics, where he discussed the properties of air in a very general form (Desaguliers, 1734–1744). He then gave further details in an

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25 "sapere più che si possa l'Istoria di tutti gli Esperimenti, che sono stati fatti, li modi, gli artificii, e le Macchine adoperate. Di più il successo degli Esperimenti medesimi, e le conseguenze che ne sono state fatte per la Filosofia Naturale, o per la Matematica. Questo è un Mare Magnum, che dipende da gran quantità di Libri, e da lunga lettura et applicazione". Poleni, G., undated manuscript: BNVe, It, IV, 592 (= 5555), f° 128–130.

26 "secondo le divisioni ideate dalli Filosofi". Poleni, G., undated manuscript: BNVe, It, IV, 592 (= 5555), f° 128–130.

27 "secondo l'ordine delle cose naturali e matematiche". Poleni, G., undated manuscript: BNVe, It, IV, 592 (= 5555), f° 128–130.

28 "gli Esperimenti appartenenti alla Hidrostatica, gli Esperimenti appartenentj alla Meccanica delle Macchine, gli Esperimenti appartenenti all'Optica, gli Esperimenti appartenenti al Vacuo, e così successivamente". Poleni, G., undated manuscript: BNVe, It, IV, 592 (= 5555), f° 128–130.

29 "questo credo che sarebbe l'ordine migliore". Poleni, G., undated manuscript: BNVe, It, IV, 592 (= 5555), f° 128–130.

30 For example, Desaguliers explained he did not present his lectures on optics in his *Course* because his text was already too long, and he preferred providing his readers with references to other publications (Desaguliers, 1734–1744, vol. 2, pp. vi–vii).

"addenda" at the end of the second volume of his treatise. 's Gravesande placed electricity within the chapter about fire ('s Gravesande, 1720–21, 1731, 1751), Musschenbroek had a specific section on it just after mechanics (Musschenbroek, 1734, 1739, 1751), while Nollet dedicated to electricity about half of the last volume of his *Leçons de physique expérimentale* (Nollet, 1743–1764). This not only reflected the personal interests of the various lecturers – Nollet was particularly involved in cutting-edge researches in electricity – but also the changings occurring in the field: from the 1740s, electricity enjoyed a growing popularity, underwent important developments and became a prominent field of experimental philosophy. More generally, all authors insisted on the importance of having their lectures continuously updated with new experiments, as well as with corrections and clarifications because, as Nollet, underlined, "discoveries are multiplying, errors can be corrected, doubts can be clarified" (Nollet, 1743, p. x).[31] Finally, it is worth noting that, besides a section on hydrostatics, some authors, like Nollet and Musschenbroek, also introduced a section on "water", dealing with some properties of water: such a section, together with the section called "fire", highlights the transition that was going on, outlined by Poleni, from the "old" philosophical divisions related to the four elements to the new way of structuring experimental philosophy courses.

Not only was the general structure of eighteenth-century experimental philosophy courses totally new, but the structure of each lecture was new as well, as various treatises show. Lectures started with a general introduction on the given topic, followed by some experiments. The professor described how to prepare the experiments and the instruments used, then examined the effects, provided the necessary explanations and often showed the links, if any, with everyday life or natural phenomena. In the textbooks, illustrations were usually inserted, in order to show the actual instruments that were used in presence. Such illustrations became more and more numerous and refined as new editions and new treatises were published.

With a new clear structure, a clear content and well defined objectives, the new courses marked a dramatic turn with respect to previous experimental lectures. For example, Sturm's 1676 treatise *Collegium Experimentale, Sive Curiosum* simply presented a list of experiments and instruments disconnected from one another, such as "Camerae obscurae, Tubi Torricelliani, seu Baroscopii, Antliae Pneumaticae, Thermometrum, Hygroscopiorum, Telescopiorum, Microscopiorum" (Sturm, 1676). As for Polinière's volume *Expériences de Physique,* it discussed mechanics, pneumatics and optics, but also experiments on the human body and on animals, while the Anglo-Dutch lecture-demonstrators focused on a much narrower field, contributing to make physics in its current sense emerge as a discipline in itself. Scholars were actually trying to define this new field, and Nollet wrote for instance that "[t]he first of these two sciences [experimental philosophy] sets out to shed light on the mechanism of nature; the

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31 "les découvertes se multiplient, les erreurs se corrigent, les doutes s'éclaircissent" (Nollet, 1743).

last [natural history] offers us, so to speak, an inventory of our riches" (Nollet, 1752, p. xlvii).[32]

A shift in the sense of the term "physics" also occurred in those years and experimental philosophy treatises contributed to this shift. As we have just seen, Polinière intended "physics" in its original sense, i. e. as a synonym of "natural philosophy", thus encompassing all aspects of the natural world. 's Gravesande's 1721 book, *Physices elementa mathematica experimentis confirmata*, still remained very close to Newton's *Philosophiae naturalis principia mathematica*: "physics" was still a synonym of "natural philosophy". The title of the English translation of the treatise is in fact *Mathematical elements of natural philosophy* (1721). However, the French version of the textbook, published in 1747, was simply entitled *Eléments de physique*, thus confering to the term "physique" its current meaning. As for Desaguliers, he gave his new course the title *A Course of experimental philosophy* in 1734, while Nollet called his main textbook *Leçons de physique expérimentale* (Nollet, 1743–1764). Experimental philosophy and experimental physics thus became synonyms. In the same years, Musschenbroek published his *Elementa physicae* (1734), which became *Essai de Physique* in the French revised version (1739). The term "physics" was thus confusingly used to indicate not only natural philosophy but, more specifically, the new narrower discipline that was emerging: physics was acquiring the sense it has today.

As we already mentioned, eighteenth-century professors of experimental philosophy were well aware they were setting up a totally new way of teaching. They worked on the basis of accurate reflections and paid a lot of attention to the needs of their audience, but it may be worth adding a few more details. For instance, Nollet wondered whether it was worth preparing some 'cahiers' – lecture notes in modern terms –, in order to read or recite them. However, he himself objected: "Who does not know that the best things, when presented in this way, make the audience fall asleep and hardly ever catch the attention they deserve?",[33] and he added that it is better "to get into the habit of working and speaking at the same time, and using less words than the description of facts [...] so that nobody should be afraid of interrupting a prepared speech, if one wants to make objections and ask for clarifications" (Nollet, 1738, p. xxii–xxiii).[34]

As for Giovanni Poleni, he not only used instruments during his lectures, but also cardboards where experiments and instruments were drawn, so that he could enhance the quality of his explanations. He also insisted on the fact he could not hold the new

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32 "La première de ces deux Sciences [experimental philosophy] entreprend de nous dévoiler le méchanisme de la nature; la derniere [natural history] nous offre, pour ainsi dire, l'inventaire de nos richesses" (Nollet, 1752).

33 "Qui est-ce qui ne sçait pas que les meilleures choses données de cette manière endorment à la fin les Auditeurs, & ne se concilient que rarement l'attention qu'elles peuvent mériter?"(Nollet, 1738).

34 "de se former une habitude d'opérer en parlant, & même d'employer moins les paroles que l'exposition des faits [...] de façon que chacun, quand il voudroit faire des objections, & demander des éclaircissemens, n'eût point à craindre d'interrompre un discours étudié" (Nollet, 1738).

lectures at home, as this was uncomfortable and unfair for his students. He started lecturing at the university, but described "the sorrow of those many who were there to watch, but could not see anything".[35] Poleni thus asked the Republic of Venice to have an adequate place and he was charged, together with his friend, the physician Giovanni Battista Morgagni, with planning and supervising renovation works in the historical building of the University, the *Palazzo del Bo:* specially designed rooms were then set up to store instruments and carry out experiments, and a theatre was built for the lectures. In the very detailed letters that Poleni sent to Venice to describe how works were going on, the Venetian scholar explained that he limited the theatre to one hundred seats, because "if the place [the theatre] was larger, part of the audience would be too far and could not learn, as experiments are meant to be seen".[36]

The instrument- and practice-related issues

Besides the pedagogical challenges we just discussed, the first professors of experimental philosophy also faced problems related to the scientific instruments they used in their lectures. As Nollet pointed out in 1770, "Experimental Physics cannot do without Instruments" (Nollet, 1770, p. ix),[37] and one of the main problems was that such devices were not only extremely expensive but also difficult to find. For the first English lecture-demonstrators, the resources provided by the local scientific instrument market, which was flowering in London at that time, were crucial. 's Gravesande and Musschenbroek could rely upon Jan van Musschenbroek's workshop in Leyden, very active in those years (de Clercq, 1997) but, in the rest of Europe, only a few craftsmen were able to make reliable scientific devices. As lecture-demonstrations became very popular, the demand for scientific instruments exploded, so that the situation became critical. Nollet mentioned, in 1770, that the "Schools of Physics which a noble emulation brings forth every day in the various Universities of the Kingdom", had problems to get instruments, "not finding in the Province workmen who could do this kind of work" (Nollet, 1770, p. xi).[38] Some years before, to acquire the devices he needed for his own lectures, Nollet himself had set up a workshop of his own, explaining that:

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35 "il dispiacere di que' molti, li quali stavano per vedere, né però vedevano punto". Poleni, G., letter to Bianchi, 1 July 1739: Venice, Archivio di Stato (ASVe), *Riformatori allo Studio di Padova*, Filza 211.

36 "se il luogo fosse maggiore, quelli che fossero di più per necessità dovrebbero essere più lontani, né sarebbero a portata di ricavar frutto, perché gl'esperimenti sono per quelli che stanno vicini a poterli vedere". Morgagni, G. B., and Poleni, G., letter to the *Riformatori*, 13 September 1739: ASVe, *Riformatori allo Studio di Padova*, Filza 211.

37 "La Physique Expérimentale ne peut se passer d'Instruments" (Nollet, 1770).

38 "Ecoles de Physique qu'une noble emulation fait naitre tous les jours dans les diverses Universités du Royaume", had problems to get instruments "ne trouvant point dans la Province d'ouvriers faits à ce genre d'ouvrage" (Nollet, 1770).

"I myself took a file and a chisel, I trained and guided workers so they could help me; I aroused the curiosity of several Lords who put my works in their own Cabinets; I obtained a sort of voluntary donation; in other words, I do not deny that I made two or three instruments of the same kind so that I could keep one for me" (Nollet, 1738, p. xviii–xix).[39] Nollet actually wrote an entire treatise, *L'art des experiences*, focusing on detailed and technical descriptions of instruments and instrument-making techniques (Nollet, 1770). In Padua, Poleni faced similar problems as well. To set up his Cabinet of Physics, he obtained funds from the Republic of Venice, but these were not sufficient to buy all the instruments he looked for. He thus purchased only some of his devices from well-known workshops, like Nollet's and Musschenbroek's, bought some others from a few Italian craftsmen, and had the majority of his instruments made on-site, according to the descriptions provided by the physics treatises of the time (Figs. 3 and 4). The financial reports Poleni regularly sent to the Venetian Senate show that he had several craftsmen – a goldsmith, a blacksmith, a wood turner, a glass blower and a



Fig. 3 One of the instruments made in Padua by various craftsmen under Poleni's supervision in the 1740s. Based on Pieter van Musschenbroek's design, it was meant to measure the strength of materials. Giovanni Poleni Museum, University of Padua.

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39 "J'ai pris moi-même la lime & le ciseau, j'ai formés & conduits des ouvriers pour m'aider; j'ai intéressé la curiosité de plusieurs Seigneurs qui ont placés de mes ouvrages dans leurs Cabinets; j'ai levé une espece de contribution volontaire; en un mot, je ne le dissimule pas, j'ai fait deux ou trois instruments d'une même espece afin qu'il pût m'en rester un" (Nollet, 1738).

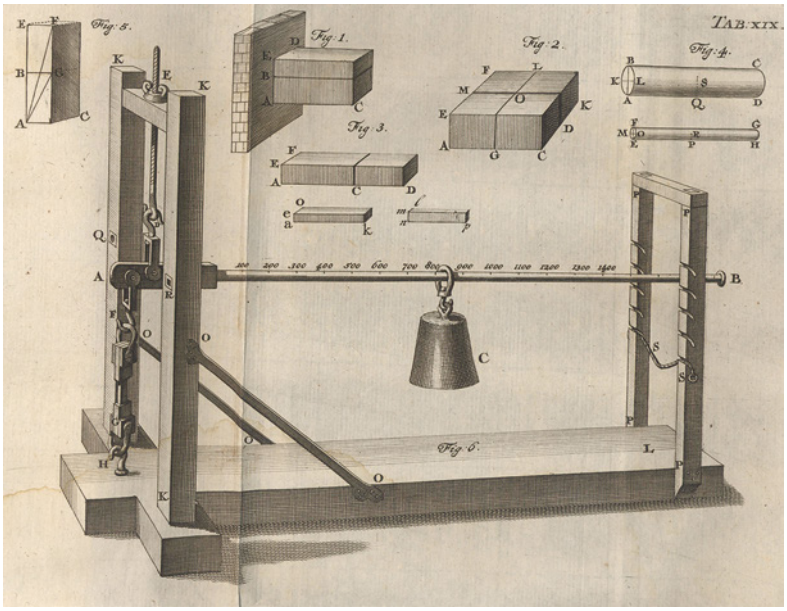


Fig. 4 The instrument devised by Musschenbroek to measure the strength of materials (Musschenbroek, 1729).

joiner – work for him under his own supervision.[40] The quality of the surviving instruments shows that Poleni was skilful enough to successfully plan, supervise and guide the construction of scientific instruments (Talas, 2013).

Poleni actually underlined that, to provide experimental philosophy lectures, a teacher should not only have a good theoretical knowledge, but experience in practicing with instruments and "ingenuity in his hands".[41] Nollet insisted on this point too, specifying that lecture-demonstrators were expected not only to have the skills to use instruments, but also to be able to preserve them, find their defects and correct them (Nollet, 1752). He underlined that professors needed to have a great knowledge of machines, because choosing, using and preserving instruments cause "a perpetual torment to anyone who does not know them, I should say, better than the artist who made them" (Nollet, 1752, p. lxxxvii).[42] Nollet explained that the various devices in use in those years had been invented by scientists living at different times and with different points of view, so that one had to be able to evaluate the reasons why those scientists chose one given shape and mechanism. He pointed out that "what one may find most tedious & most embarrassing in the

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40 "Note e ricevute delle spese fatte per l'artificiosissima machina, con cui si fanno e si mostrano gli esperimenti delle forze centrali": Padua, Archivio Università di Padova (AUP), busta 591.

41 "ingegno alle mani". Poleni, G., letter to Morosini, undated : BMVe, ms. it., IV, 592 (= 5555), c. 191.

42 "un tourment perpétuel à quiconque ne les connoit pas aussi-bien, je devrois dire, mieux que l'Artiste qui les a faits" (Nollet, 1752).

Art of Experiments, is the maintenance and repair of Machines" so that, to be a good professor of experimental physics, "one must be almost as much initiated in the Mechanical Arts as in the knowledge of natural effects" (Nollet, 1752, pp. lxxxviii–lxxxix).[43]

Finally, a good lecture-demonstrator was also expected to design by himself new instruments and introduce new experiments, as Poleni pointed out: "It is necessary, in establishing a new Experimental School, to begin with the things done by others, use instruments that are available, and have others made according to the opportunity. We must then endeavour to invent new instruments and experiments".[44] Poleni devised for instance a device intended to demonstrate the law of falling bodies by means of a flow of mercury. He sent a copy of this instrument in 1745 to Antonio Leprotti, the Pope's personal secretary, with a precise list of instructions explaining how to use it. Poleni and his correspondents actually exchanged instruments quite often, just as they sent and received books and papers. They sent around both teaching devices, like Poleni's mercury instrument, or research instruments – for example, Poleni and Joseph-Nicolas Delisle, who was at the time at the Academy of St Petersburg, exchanged thermometers and barometers to discuss their ongoing researches. The transfer of scientific knowledge and teaching practices was not only based on travels, transfers of papers, books and letters, but also on the exchange of scientific instruments.

The impact of eighteenth-century experimental philosophy lectures – Concluding remarks

We saw that the new lecture-demonstrations that emerged and rapidly diffused in the eighteenth century were widely successful, but what can we say about their actual impact?

Let us recall, first of all, that these lectures marked a crucial turn in the history of science teaching: new content was introduced and radically new teaching practices were developed, based on the first lecture-demonstrators' careful reflections. The circulation of ideas, knowledge, treatises, papers and instruments contributed to the setting up of the new teaching practices, leading to global patterns for experimental philosophy courses: the structure of the new courses and lectures became a standard in most universities by the end of the eighteenth century, and many instruments became classical in most cabinets of physics – let's mention for instance devices like the

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43 "ce que l'on trouvera peut-etre de plus pénible & de plus embarassant dans l'Art des Expériences, c'est l'entretien et la reparation des Machines" so that, to be a good professor of experimental physics, "il faut être Presque autant initié dans les Arts méchaniques que dans la connaissance des effets naturels" (Nollet, 1752).
44 "Bisogna nell'instituire una nuova Scuola Esperimentale principare dalle cose fatte dagli altri, et andar adoperando li stromenti che si avessero, e facendone fabbrcare degli altri secondo l'opportunità. Bisogna poi procurar d'inventare degli Istromenti e degli Esperimenti nuovi". Poleni, G., undated manuscript: BNVe, It, IV, 592 (= 5555), f° 128–130.

inclined plane used to show the tautochronism of the cycloid, Heron's fountain, or Magdeburg hemispheres. These novelties shaped physics teaching for the following centuries up to today. The structure of the courses established during the eighteenth century actually remained almost unchanged during the whole nineteenth century, and is still widespread in schools today. Moreover, many of the teaching instruments designed in the eighteenth century remained in use during the nineteenth century and part of the twentieth century, and several of them are still sold and used today for physics teaching. This is the case, for instance, of the so called 's Gravesande's ring, used to show the dilatation of solids, the feather and guinea apparatus, that demonstrates how different bodies fall in the vacuum, or the bell in the vacuum demonstration.

However, it is also important to underline that, besides their globally shared aspects, experimental philosophy courses were also marked by local specific peculiarities, for instance in the use of instruments – let's recall Poleni's device for the law of falling bodies. Such global and local features emerged in previous studies (Bennett & Talas, 2013), but it would be worth widening the research by examining more of the huge network of people who practised experimental philosophy demonstrations in those years.

To further evaluate the impact of the new eighteenth-century teaching practices, let us add that, as we already mentioned, the new lectures contributed to narrow the meaning of the term "physics" and to make physics in its modern sense emerge as an independent field of knowledge.

Furthermore, though physics became extremely popular in the course of the eighteenth century – Nollet underlined that "Thanks to the good taste which characterizes our century, I do not need to prove that Physics is useful" (Nollet, 1743, p. xxxvii) –,[45] several scholars were very concerned about an enduring lack of scientific knowledge in society. Nollet himself complained in 1738 that there were too many people who "are at the mercy of all popular mistakes, worried by the most ridiculous fears, subject to any wonderful falsehood and to all the quackeries that may be used to deceive them" (Nollet, 1738, p. xxxvi).[46] A few years later, Voltaire shared a similar concern: "There are a hundred thousand souls in Paris who, in blowing fire out of their chimneys, have never even thought of the mechanism by which the air entering their bellows then closes the valve attached to it. Ladies, princesses and queens spend part of the morning looking at their mirrors, without imagining that there are lines of light that form an angle of incidence equal to the angle of reflection" (Voltaire, 1768, p. 125).[47] Desaguliers

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45 "Graces au bon goût qui regne dans notre siècle, je puis me dispenser de prouver que la Physique est utile" (Nollet, 1743).

46 "livrées à toutes les erreurs populaires, préoccupées des craintes les plus ridicules, susceptibles de tout le faux merveilleux & de toutes les charlataneries dont on voudra se servir pour les tromper" (Nollet, 1738).

47 "Il y a cent mille âmes dans Paris qui en soufflant le feu de leurs cheminées, n'ont jamais seulement pensé à la mécanique par laquelle l'air entrant dans leur soufflet ferme ensuite la soupape qui lui est attachée. Les dames, les princesses, les reines passent une partie du matin à leur miroir, sans imaginer qu'il y a des traits de lumière qui forment un angle d'incidence égal à l'angle de réflexion" (Voltaire, 1768).

went further and described how he tried to spread knowledge about experimental philosophy not only in universities, academies, *salons* and royal courts, but also in lower classes of society. He wrote for instance that "[a]bout 15 Years ago a German of middle Size, and but ordinary Strength, shew'd himself at the *Blue Posts* in the *Hay Market*, and [...] pass'd for a Man of uncommon Strength, and got considerable Sums of Money by the daily Concourse of Spectators. After having seen him once, I guess'd at his manner of imposing upon the Multitude; and being resolved to be fully satisfied in the Matter, I took four very curious Persons with me to see him again, *viz.* the Lord Marquis of *Tullibardin*, Dr. *Alexander Stuart*, Dr. *Pringle*, and a mechanical Workman, who us'd to assist me in my Courses of Experiments". Desaguliers and his friends observed "nicely all that he did, and found it so practicable" that they were rapidly able to perform the German's feats by themselves, then showing "some of the Experiments before the Royal Society; and ever since, at my Experimental Lectures, I explain the Reason of such Performances" (Fig. 5). Desaguliers then proudly concluded that "I don't hear that any of these *Sampsons* have attempted since to impose upon People in the same manner in or near London" (Desaguliers, 1734–44, vol. 1, p. 255).

Quite naturally, the activities of these first lecture-demonstrators not only contributed to make science public in *salons* and courts, beyond academies and universities, but also marked the beginnings of a kind of more generalised, conscious and systematic

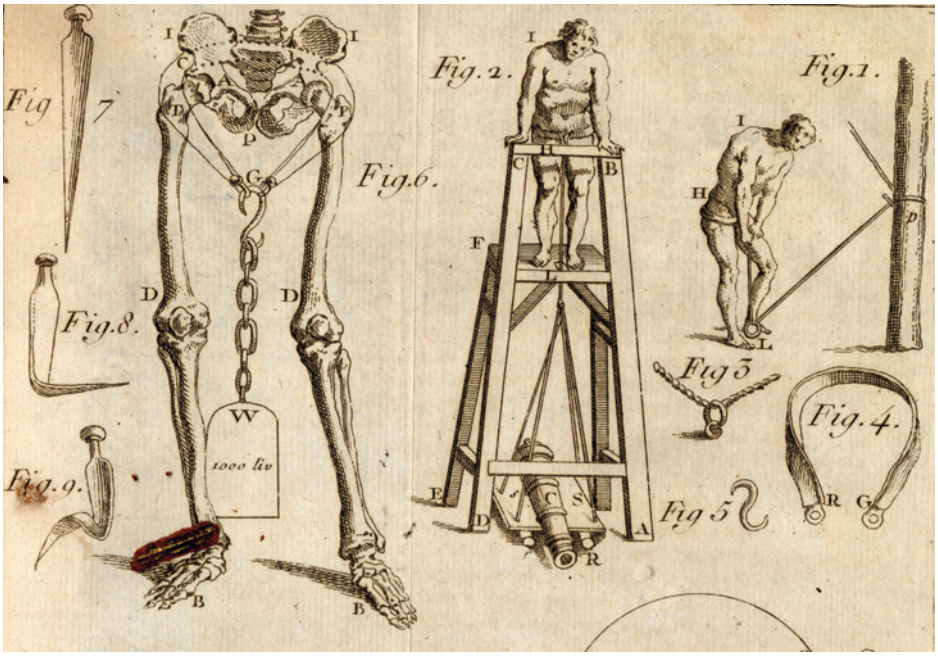


Fig. 5 On the right, some of the performances on which Desaguliers shed light. On the left, sketches showing the studies carried out by Desaguliers to show that no particular strength was needed (Desaguliers, 1751).