Approaching the history of science through its images in science teacher education

The case of the pneumatic apparatus

Pere Grapí

Abstract The search for appropriate formats to present the history of science to science teachers is far from a minor issue. This paper addresses the question of the suitability of historical images of science when used as teaching resources. Discussions about images enable students to discover elements that can help them to both generate and share explanations. The objective is not so much to teach the history of science as to make use of it with an alternative approach by means of homeopathic doses through images. Joseph Priestley's 1775 image of the pneumatic apparatus may be suitable as a guiding resource to promote discussion about issues such as the nature of the aerial state, the interaction between theory and apparatus design, or the constraints and risks of the materials used in the making of apparatuses.

Keywords **Gases, pneumatic apparatus, science teacher education, historical images.**

Résumé **Enseigner l'histoire des sciences par les illustrations : l'exemple de l'appareil pneumatique**
Pour les professeurs, la recherche de supports appropriés pour enseigner l'histoire des sciences est loin d'être une préoccupation mineure. Les discussions autour d'images peuvent en effet aider les étudiants à découvrir et partager des connaissances. L'objectif est d'enseigner l'histoire des sciences par petites touches grâce à cette méthode alternative. Par exemple, l'image de l'appareil pneumatique de Joseph Priestley datée de 1775 permet d'aborder la nature de l'air, l'interaction entre la théorie et la conception de l'appareil, ainsi que les contraintes et risques inhérents.

Mots-clés **Gaz, appareil pneumatique, enseignement des sciences, images historiques.**

The idea for this article comes from my own experience acquired from the years I have spent in science teacher education and is addressed to the training of science teachers in the history of science. Since prospective and in-service science teachers are not expected to have enrolled in historical courses during their university careers, post-graduate courses in science teacher education, including a number of sessions devoted to the history of science, are intended to fill this training gap. The use of inscriptions as teaching resources in these kinds of courses has proved to be advantageous. Illustrations such as paintings, photographs, tables, drawings, diagrams, formulas, etc. help students to discover for themselves some aspects of the images that may serve to promote discussion and participation, thereby enabling them to share explanations. Hereafter, the term "image" will be employed in a very broad sense as a synonym for "non-verbal resource" [1].

The purpose of this paper is to explore the idea of using the history of science through its historical images rather than teaching the history of science by means of academic contents. Historical images may facilitate the introduction and discussion of important issues such as the scientist's mental framework, his or her actual practice of science, the material culture or the spaces of scientific practice of the time. For instance, the allegory from the frontispiece of the book *Almagestum Novum* (*figure 1*), written by Giovanni Batista Riccioli in 1651, can be used to discuss the world-systems

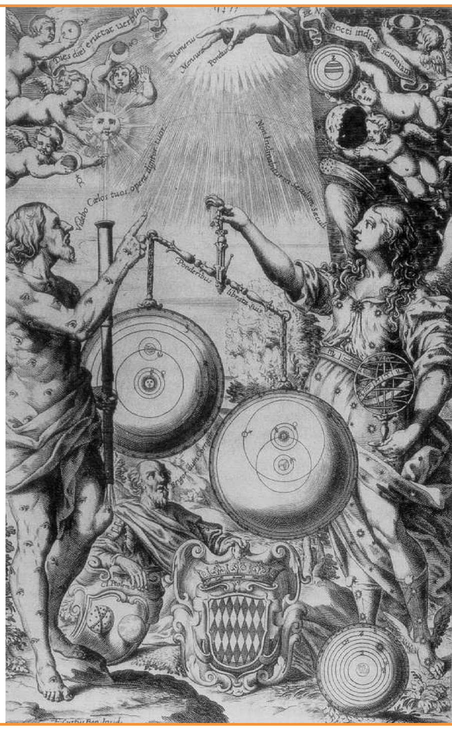

Figure 1 - Detail from the frontispiece of Riccioli's *Almagestum Novum* (Bologna, 1651).

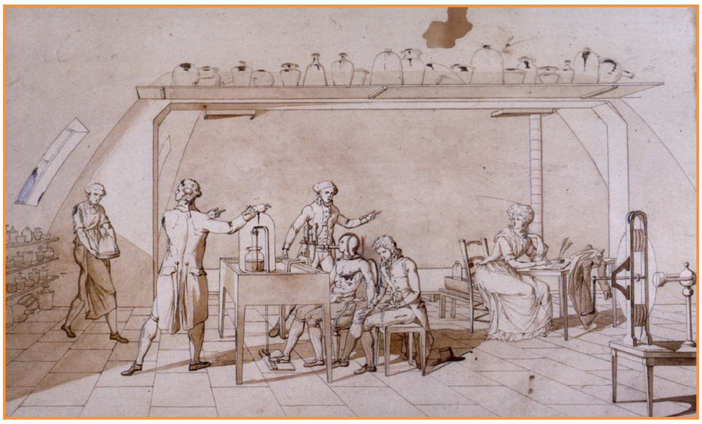

Figure 2 - One of the two drawings by Marie-Anne Paulze (Madame Lavoisier), c. 1790.

of Ptolomey, Copernicus and Brahe [2]. In addition, either of the two drawings (*figure 2*) by Madame Lavoisier, illustrating experiments on human respiration that were conducted by Lavoisier and his colleagues in his laboratory at the Arsenal, can be used to discuss the division of work and roles in laboratory life during Lavoisier's time [3].

Priestley's pneumatic apparatus: a historical image as a teaching resource

With this purpose in mind, the image of Joseph Priestley*'s pneumatic apparatus, published in 1775 in his work *Experiments and Observations on Different Kinds of Air* (*figure 3*), has been chosen as a starting resource with the aim of immersing science teachers in some aspects of the history of science, particularly in the history of chemistry, and may be of great help to them in their training.

While images can be used in different ways to enable the audience to understand what is being said, in the field of science, at least, images are not regarded as self-sufficient descriptions. At this point, a distinction should be made between an initial stand-alone image without any accompanying text, such as Madame Lavoisier's drawings, and images imbedded in a text. In this latter case, any adequate interpretation of the image requires an understanding of the text in which it appears [4]. This means that our image of Priestley's pneumatic apparatus should be accompanied by a corresponding oral or written description.

In what follows, an abridged version of Priestley's description of his pneumatic apparatus is provided. Not all the elements depicted in the figure are presented, and Priestley's own terminology has been preserved as far as possible. Together with the image of the pneumatic apparatus, this description would constitute the working material for a training session devoted to the history of chemistry for science teachers [5].

Firstly, according to Priestley, experimental procedures could not be fully described in words and only after much practice a person could be able to carry out complex experiments easily. His pneumatic apparatus (*figure 3*) consisted of a wooden oval-shaped trough (a) filled with water, at one end of which there was a wooden shelf (bb) under the water.

For the storage of the several *kinds of air*, Priestley used cylindrical glass jars (c), which once removed from the trough he placed in pots or tea-dishes of different sizes (2). The procedure consisted of immersing the dish in the water and sliding the jar into the dish so that both could be removed

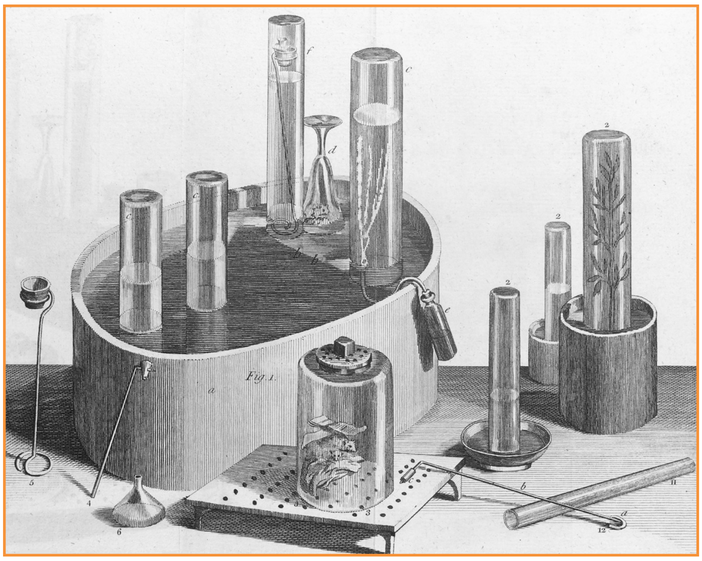

Figure 3 - Joseph Priestley's pneumatic apparatus. From *Experiments and Observations on Different Kinds of Air* (London, 1775), Frontispiece.

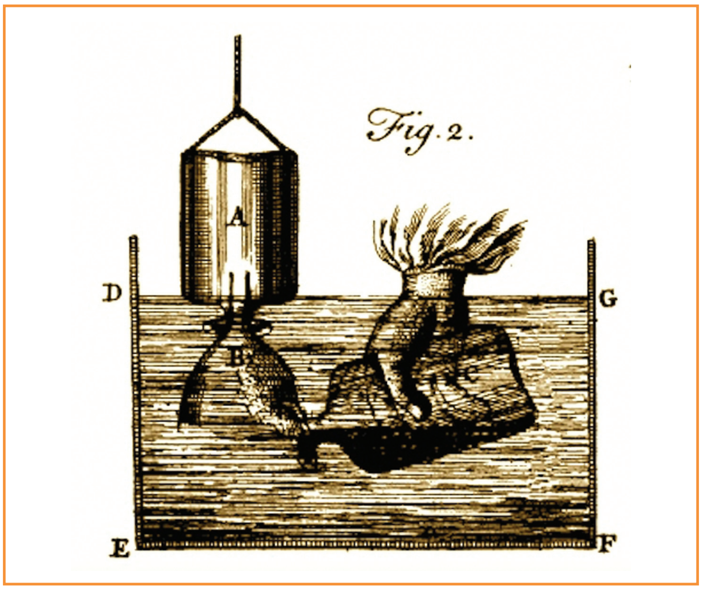

Figure 4 - Cavendish's device for transferring gases. From *Philosophical Transactions* (1766), vol. 56, plate 7, p. 141.

together. The main use of the tea dishes was to transfer a jar from one place to another. When it was necessary to support a small pot at a considerable height inside a jar, a wire stand (5) was used, a utensil that could easily be bent and adapted to any height (f).

Another usual operation consisted in pouring air from a vessel with a wide mouth into another with a narrow mouth, in which case a funnel (6) was needed. The operation first involved filling the vessel into which the air was to be transferred with water (*figure 4*). Then with one hand the mouth of this vessel together with the funnel were held under water, while the other hand was used to pour the air upward so that it rose through the funnel into the vessel, thereby displacing water within [6].

In order to generate and collect air by the dissolution of metals by acids or any other process, materials were placed inside a small flask equipped with a narrow glass tube bent and inserted through a perforated airtight cork (e) (*figure 3*).

The end of this tube was introduced under the mouth of a cylindrical jar (c) placed on the shelf and into which the released air could be collected. Heat could be applied to the small flask when necessary by means of a candle. Alternatively, the flask could be immersed in a water bath filled with warm or boiling water. One of the risks involved in this operation was that the flask might break due to a sudden application of heat. For the collection of the kinds of air that are soluble in water, Priestley took advantage of Cavendish's innovation by using mercury instead of water. In this way, even extremely water-soluble airs could be isolated with the aid of the pneumatic apparatus.

Finally, in an experiment to determine if a mouse could live in any kind of air, he found it very convenient to use the hollow part of a tall beer-glass filled with the air (d). The mouse was held by the back of the neck and drawn through the water into the glass. According to Priestley, if the air was good the mouse would survive, having suffered nothing by its passage through the water. He also found that a plant could be put into a vessel with any kind of air (2).

In order to keep the mice comfortably, they were placed inside a glass jar (3) open at both the top and bottom and standing on a tin plate covered with another plate of the same kind. Both the lower and upper plates were perforated, which allowed for ventilation. Small pieces of paper or washcloth were also placed inside for cleaning purposes.

An alternative approach to the history of chemistry

The next phase in the training session would consist in proposing a number of general topics arising from the image of Priestley's pneumatic apparatus and its accompanying description, which could be presented to students for the purposes of discussion. Such topics might be as follows:
- the interaction between theoretical views and the design of experimental devices;
- the versatility of an experimental device;
- materials used in the construction of experimental apparatuses: their constraints and risks;
- the use of animals for experimentation;
- tacit knowledge in the practice of chemistry.

By focusing on the first topic, the interaction between theory and the design of experimental devices, the session with trainee teachers would continue with an open question to initiate a debate. For instance, the trigger question might be as follows: "*Have you noticed the absence of the term «gas» in this description concerning gaseous substances?*"

Of course, the absence of the term "gas" or "gases" in reference to the standard third state of matter is quite noticeable [7]. Indeed, Priestley refers to his pneumatic apparatus as an apparatus to "generate and collect several *kinds of air*". The fact is that until the end of the 18th century, chemistry remained a two-dimensional discipline, attention being paid primarily to solid and liquid materials and neglecting what we now call "gases". The variety of terms used in the past to refer to gases – such as spirits, airs, exhalations, fumes or vapours – is evidence of the lack of understanding of the gaseous state. According to the prevailing Aristotelian philosophy, common air was regarded as an elementary substance rather than one exemplifying the gaseous state of matter. Furthermore, common air was very far from being perceived as a mixture of gases. The different *airs* or *kinds of air* were first recognized by their external qualities. For this reason, they were referred to as *inflammable air*, *fixed air* or *respirable air*, on the assumption that they all constituted atmospheric air in varying degrees of purity and containing alien particles that modified their elasticity [8].

At this point in the session, the teacher-trainer could bring the relationship between theory and the configuration of the pneumatic apparatus to the attention of the audience by recalling the first steps in the development of the pneumatic apparatus. The prototype of a pneumatic apparatus was a device invented by Stephen Hales in 1727 for isolating and measuring the amount of air released from different materials by heating or fermentation. The fact is that this was an apparatus for *washing* airs rather than collecting them. In brief, the basic idea or inspiration for the pneumatic apparatus resembled an *air washing machine* for purifying those released airs by intercepting and retaining their impurities in the water. It is therefore clear that the prototype of the pneumatic apparatus was theory-laden [9].

Ironically, however, the purifying water of Hales's device became unsuitable for collecting water-soluble gases such as *fixed air* (carbon dioxide) or the *volatile alkali* (ammonia). To overcome this difficulty, Cavendish suggested substituting mercury for water in the apparatus, as mentioned above. Nevertheless, it was Priestley who fully developed this innovation to isolate water-soluble gases such as hydrogen sulphide, ammonia or sulphur dioxide. In any event, in this context, it is worth noting that mercury was more expensive than water, and it became advisable to replace mercury with water covered by a layer of oil [10].

For this stage in the session, teachers should be acquainted with some theoretical aspects of late 18th century chemistry. At that time, early speculations on airs as variations of atmospheric air had evolved in the light of the phlogiston theory. Phlogiston was an intangible fluid entity that was assumed to be given off in combustion, and for a time the theory was accepted to interpret the nature of gases. Thus, it was understood that the air that enabled a mouse to live longer than in common air was *dephlogisticated air* (i.e. dioxygen), whereas the gas later known as nitrogen was *phlogisticated air*. In accordance with this theory, atmospheric air consisted essentially of a mixture of phlogisticated and dephlogisticated air. So once again, a new theoretical framework came to influence the experimental design of the pneumatic apparatus.

The early interpretation of combustion in terms of the phlogiston theory led to the use of water again in the apparatus instead of mercury. It was therefore believed that, during the burning of materials, such as a piece of phosphorous placed inside a bell jar inverted over water in an apparatus (*figure 5*), phlogiston was released and saturated the common air. On the other hand, certain hypothetical fixed air was given off from this same air and was absorbed by the water, thereby causing a contraction in volume of the air sample. Accordingly, it was believed that if experimenters wished to measure this decrease in volume, they needed to use water instead of mercury. However, from 1773 onwards, when Lavoisier began to suspect that no fixed air was given off from the common air during burning, experiments involving combustion were commonly performed over mercury in the pneumatic apparatus [11].

Thus, Hales's conception of his pneumatic apparatus prototype, together with the alternating use of water and mercury as a medium for the combustion of phosphorous in the pneumatic apparatus, are cases that serve to exemplify the influence of a theoretical framework on the design of an experimental device.

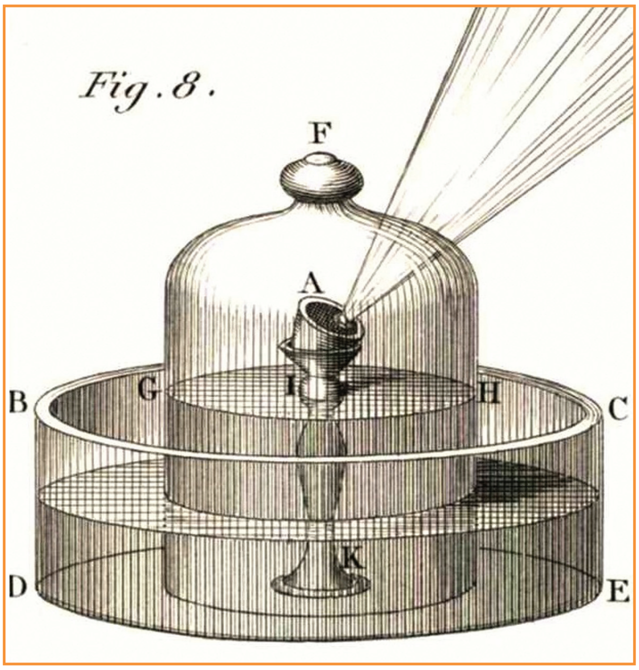

Figure 5 - Lavoisier's experiment on the combustion of phosphorous. From *Opuscules physiques et chimiques* (Paris, 1774), vol. 1, plate 2.

By way of conclusion

Any of the above mentioned topics suggested for the encouragement of discussion would be a suitable candidate for an exploration of the history of chemistry. Images are powerful resources because they are able to provide insights and interpretations on a subject, thereby enhancing and complementing those arising from textual sources alone. One may readily realize the importance of images when one considers how much harder it is to convince when we are deprived of them [12]. It is for all these reasons that historical images of chemistry can furnish a basic teaching resource with which science teachers may approach the history of chemistry. We are fortunate that the history of chemistry is rich enough to provide us with significant images to assist in the achievement of this aim.

Notes and references

* See his biography in: Fauque D., Joseph Priestley (1733-1804), *L'Act. Chim.*, **2017**, *421*, p. 60.

[1] Mazzolini R.G., *Non-Verbal Communication in Science Prior to 1900*, Leo S. Olschki, **1993**, p. vii.

[2] Grapí P., *Innovative Methods for Science Education: History of Science, ICT and Inquiry Based Science Teaching*, O. Bruneau, P. Grapí, P. Heering, S. Laubé, M.R. Massa-Esteve (eds), Frank & Timme, **2012**, p. 57-80.

[3] Beretta M., Imaging the experiments on respiration and transpiration of Lavoisier and Séguin: two unknown drawings by Madame Lavoisier, *Nuncius*, **2012**, *27*, p. 163.

[4] Lynch M., *Representation in Scientific Practice*, M. Lynch, S. Woolgar (eds), The MIT Press, **1990**, p. 153-186.

[5] Priestley J., *Experiments and Observations of Different Kinds of Air*, J. Johnson, London, **1775**, p. 7.

[6] An image from a paper by Cavendish is shown to illustrate this operation. In this image, the vessel is not held with the hand but it is suspended from a string.

[7] Jan Baptist van Helmont was responsible for the introduction of the term "gas" (from the Greek *chaos*) to refer to those "spirits" produced by chemical operations; in particular, distillations that were difficult to retain in vessels. Lavoisier recovered the word more than a century and a half later.

[8] Badash L., Joseph's Priestley's apparatus for pneumatic chemistry, *Journal of the History of Medecine*, **1964**, *19*, p. 139; Parascandola J., Ihde A.J., History of the pneumatic trough, *Isis*, **1969**, *60*, p. 351.

[9] The importance of the pneumatic apparatus as a device for the collection of pure gases was not recognized until the works of chemists and natural philosophers such as Joseph Black in 1755 and Henry Cavendish in 1766; the latter isolated *inflammable air* (hydrogen), the first of many gases to be discovered with the aid of the pneumatic apparatus.

[10] Crosland M., *Instruments and Experimentation in the History of Chemistry*, F.L. Holmes, T.H. Levere (eds), The MIT Press, **2000**, p. 79-104.

[11] Holmes F.L., *Antoine Lavoisier. The Next Crucial Year. Or, The Sources of His Quantitative Method in Chemistry*, Princeton University Press, **1998**, p. 84.

[12] Latour B., *Representation in Scientific Practice*, M. Lynch, S. Woolgar (eds), The MIT Press, **1990**, p. 19-68.

Pere Grapí
is an affiliated member of the Centre d'Història de la Ciència (CEHIC) at the Universitat Autònoma of Barcelona*.

* CEHIC, Universitat Autònoma of Barcelona, Latorre 62, 3 – 3, 08201, Sabadell, Spain.
E-mail: pgrapi@gmail.com