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History and philosophy of acidity: engaging with learners by a different route

Història i filosofia de l'acidesa: tot interactuant amb els estudiants per una ruta diferent

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abstract

The role of history (and philosophy) of chemistry is exemplified through a study of acidity. While there is much material available on the historical development of this topic, typical curricula treat the topic without reference to its origins over hundreds of years. On the other hand, the topic lends itself to explorations of a variety of philosophical perspectives, accessible to those aged 11 years old and upwards. Sufficient background is provided to give teachers confidence in this form of treatment.

Keywords
History of science, acidity, nature of science, philosophy.

resum

Aquest article exemplifica el paper de la història (i la filosofia) de la química a través d'un estudi sobre l'acidesa. Si bé hi ha molt material disponible sobre el desenvolupament històric d'aquest tema, els currículums educatius tracten el tema sense fer cap referència als seus orígens centenaris. D'altra banda, el tema es presta a l'exploració de diverses perspectives filosòfiques, accessibles als estudiants a partir dels onze anys d'edat. L'article proporciona prou referències per donar confiança al professorat sobre aquesta forma de tractament.

paraules clau
Història de la ciència, acidesa, naturalesa de la ciència, filosofia.

Introduction

The study is relevant to lower secondary school science (11-14 years old), and for all abilities. The theme of acidity is commonly treated in lower secondary schools, with occasional reference to «everyday» science such as treating wasp and bee stings. In this I aim to set the topic firmly in a historical and philosophical context. It owes its origin to work carried out for the «History and philosophy in science teaching (HIPST)» project, funded by Comenius for the European Commission (see HIPST website for details). The interpretation here has been reviewed by HIPST members but is the sole responsibility of the author.[1]

The progression of ideas about acidity beginning with the uniquely dangerous, and possibly fatal, classification based on taste, through its effect, at first, on home-made medicines that were useful as indicators of acidity, and finally searching for the magic ingredient (oxygen or hydrogen?) is an amazing story that covered many centuries, but finished nearly two hundred years ago with Humphrey Davy (1778-1829) (fig. 1). See, for example, Armitage (1906), Hudson (1992), Knight (1992), Partington (1989) and Tilden (1921) for the source of ideas in this introduction. Yet these ideas are still commonly in use today, not only in the upper reaches of schools (A level and other pre-university courses) but even

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[1] «History and philosophy in science teaching (HIPST)» project: *http://hipstwiki.wetpaint.com/* (last access: April 30th, 2013).

among some research chemists who continue to base some of their thinking about acidity in organic materials on hydrogen atoms that can be replaced by a metal. While the story can be ended at the Davy idea of replaceable hydrogen atoms, it leaves open development to other ideas.

Figure 1. Sir Humphrey Davy.

Much of the language we use about acidity, such as neutralisation, comes from medieval power politics where great powers neutralised each other through pitting equally strong armies against each other. They were thought to be equivalent to each other, and the notion of equivalence is fundamental to salt preparation. Although, at first sight, the topic appears to be phenomenological and largely descriptive, the philosophical problem of characterising a chemical class boundary through the reactions of imperfect acids is solved through induction to realise the intangible concept of the ideal or perfect acid.

Philosophical considerations of «explanation» based on cause and effect drive the search for the magic ingredient that is at the heart of all acids, even giving an element its name of *oxygen* from the Greek «sour maker». See Williams (2011) for an accessible and modern account of the philosophy of science. This search drew evidence from practical knowledge such as combustion of sulphur and phosphorus to make acrid (from Latin: 'sharp') smoke, suggesting that acids contained something that made them acidic. Of course, the role of water in taste was not considered, and, for example, sulphur oxide was named as *sulphuric acid*. Nevertheless, the oxygen containing theory was very comforting, until the chemists discovered an acid that did not contain oxygen, hydrochloric acid, when chlorine was shown to be an element. There followed a period of «accommodation» where two kinds of acids were proposed, ones containing oxygen and ones containing hydrogen. The story stops here in this study, as it did for many historical chemists who never knew about the contribution of Svante Arrhenius (1859-1927). I will give a personal outline of ideas from philosophy of science in table 1.

The case study

Introducing history and philosophy of science (HPS) in the school chemistry curriculum is a relatively recent activity for curriculum designers and researchers, compared with their work in physics. There are significant reasons for this. There are few recognised paradigm changes in chemistry compared, for example, with physics.
The usual ones quoted include the phlogiston idea, although this only lasted for fifty years in history, and quantum mechanics,

Table 1. A personal outline of ideas from philosophy of science

Theory	An overarching term for a general explanatory and causal idea that links concepts, models and laws.	The particle theory of matter explains macroscopic properties and behaviour through the properties and behaviour of individual and collections of sub-microscopic particles. Entities such as atoms, molecules and ions are central for chemists. Each of these is modelled mathematically, as visuals including drawings and animations, and by behaviours of the models such as vibrations and flexing.
Concept	An abstraction that represents a general class and contains what are considered as essential features of that class.	This idea is characterised by the lack of «a» or «the» in front of the noun. So, an acid refers to an example, but acid refers to an idealised idea about acids. Concepts also enable us to distinguish between instances and non-instances, based on these essential features. Some concepts are clear while others are described as fuzzy, that is it is very difficult to be certain about which features are actually essential. Concepts usually link with each other, such as acid, base, salt, and neutralisation to form schema.

Table 1. A personal outline of ideas from philosophy of science (cont.)

Model	A model is a representation of an event, object, system, process or idea.	Mental models are representations and are only known, partially, by the individual. To communicate mental models, they are expressed as drawings, diagrams, animations, physical objects, mathematically, gestures and orally, and by electronic systems (usually as computer software). Each expressed model is only a partial expression of a mental model. Mental and expressed models interact with each other, so that, for example, construction of a displayed formula for a compound may produce novel developments in mental models. Models can also be categorised as static or dynamic.
Law	A scientific law describes a regular pattern but without implying any causal effect.	Acids effervesce with metals such as magnesium and zinc is an example of a chemical law. Laws, typically, apply in specific and limited circumstances, such as the previous example applying in solution. While laws may imply a causal effect, and may give rise to explanatory elaboration, the law itself is without a mechanistic cause.
Phenomenon	A phenomenon is a part of the natural world that excites interest, observation with or without instruments, description and investigation, and, where possible, explanation.	The behaviour of acids in general is a phenomenon of that characterises what we call acids, and can be further sub-divided into sub-phenomena, such as effervescence with certain metals, forming salts with many metal oxides.
Data	Data is specific information, measurements or variables collected.	The most common use of data is fine-grain evidence collected by measurements, usually in physical science investigations. A broader interpretation includes coarse-grained evidence such as drawings, chemical formulae, and affective expressions such as interest and motivation, themselves also coarse-grained. Sometimes it is possible to extract fine-grained data from coarse-grained data.
Idealisation	Idealisation is a deductive process of extracting essential features and characteristics to produce an abstract idea.	Creation of the idea of ideal acid is usually made by investigation the behaviour of many specific examples of acids and then refining the central features of acid. This is described below in the case study.
Simplification	Simplification means removing complexity or elaboration.	Simplification is a common process in chemistry during the creation of the ideal. It can involve removing unnecessary concepts or entities. In acidity, one example is given by: «An acid contains hydrogen». This also illustrates a danger of over-simplification, since methane also contains hydrogen but is not usually considered an acid. This can lead to modification of the simplification, such as: «An acid contains hydrogen that is replaceable by a metal». The value of simplification is tested by its use in causal explanations, and its acceptance by the community of practitioners.
Deduction	Deduction is the process of creating a conclusion form a premise by reasoning.	If an ideal acid is a material that forms salts when reacted with many metal oxides, then when hydrochloric acid reacts with magnesium oxide to form magnesium chloride, it is behaving typically as an acid.
Inductive reasoning	Creation of a general proposition or idealisation by taking specific examples or instances and extracting essential characteristics.	Many metal oxides react with specific acids to form salts. By inductive reasoning, we create the notion of a base that includes the examples of these metal oxides.

which is, perhaps, more properly located in physics.

There are few historical artefacts that have lasted in chemistry, compared with physics which has abundant examples. Partly this is because chemistry widely used glass apparatus which is fragile and easily destroyed. Partly it is because some of the equipment, such as the balance, were considered to be so commonplace that they were simply not worth saving or recording. Partly it is because the furnaces that were used were destroyed. Finally, partly it is because many of the early chemical discoveries were based on phenomena, and not on measuring instruments.

The structure of the chemistry curriculum in schools is such that phenomenological investigations abound at junior levels, and quantitative considerations, such as calculations based on chemical formulae and chemical equations are treated and assessed in an algorithmic way. The topic is initially about acidity, a well defined topic in historical terms. I have chosen to use much of the traditional classroom material, since it is largely parallel to the historical line. Where it differs from normal teaching is in making explicit historical and philosophical incidents.

The origins of ideas about acidity are largely lost in the mists of history. An Arabic alchemist, Jābir (or Geber) ibn Hayyān (781-815), had made a wide variety of acids around AD 750. His acids included sulphuric, nitric, citric, and malonic. Many alchemists also knew about the effect of these and other acids on limestone and marble. Robert Boyle (1627-1691), in 1670, knew that an acid gives hydrogen with a metal such as zinc, or iron, although he would not be sure about the chemical nature of hydrogen. Boyle also invented the use of everyday indicators such as syrup of violets, a household medicine, for testing acidity. The term *alkali* came from the Arabic for the ashes left in the roasting pan. Boyle knew that acids and alkalis, or bases, could neutralise each other and chemists/alchemists previously had studied the salts formed. Based on alchemy, many chemists were searching for magic ingredients. Lavoisier had known that many acidic substances, such as sulphur oxide and phosphorus oxide, had been formed by burning the non-metal in his newly-named *oxygen* (Greek: 'acid maker') and that acids therefore contained oxygen. Lavoisier understood sulphur oxide to be sulphuric acid (French: *acide sulphurique*) and that its solution in water, which we now call sulphuric acid, was sulphuric acid hydrate. Not knowing the function of the water as a chemical here, it is not surprising that Lavoisier (1743-1794) did not appreciate what was going on. In 1818, Davy showed that hydrochloric acid was made up of only hydrogen and chlorine with no oxygen. This led to the idea that there were two kinds of acid, the oxoacids and the hydracids. This was resolved later in the century when it was proposed by Arrhenius that all acids in water gave off hydrogen ions, more or less (fig. 2).

Figure 2. Svante Arrhenius.

The action of creating a class of substances known as *acids* is a process of induction. Although many acids have similar properties (turning vegetable dyes red or orange or yellow, reacting with zinc and iron, reacting with carbonates, making salts with bases) there are enough exceptions to make the classification unclear. In this case study, I discuss the notion of an ideal or perfect acid, which has all the acidic features, and which we create based on the imperfect acids by their reactions. This is a challenging idea. I finish the cognitive aspect by exploring whether an acid always has oxygen or whether it might have hydrogen. This is a modest paradigm shift in chemistry, not always recognised by philosophers. Finally, I use various reflective devices to explore both their understanding of the chronology of discovery, and the philosophical processes that have taken place.

I have used links to drama in producing play scripts of historical events, and to English in the form of newspapers to present historical information. There are strong links to history in the cultural background of the scientific exploration. A homework box for students to record their thinking about idealisation on the outside provided an insight into their progress, and a card sort enabled them to discuss their view about the chronology of ideas about acidity.

History of acidity

Alchemists were aware of many acids from AD 750 onwards, although it is not clear from their writings how much they were explicit about their nature as a class of chemicals.

Acids were first classified by taste (Latin: *acetum sour*), and acids are probably the only class of chemicals to be identified this way.

The conceptual division of certain substances into acids and bases was already evident in the Middle Ages, the terms *acid*, *base*, and *salt* occurring in the writing of medieval alchemists. Acids were probably the first to be recognized, apparently because of their sour taste: the English word *acid*, the French word *acide*, the German *Sauer*, and the Russian *kislota* are all derived from words meaning 'sour'.

Boyle popularised the use of vegetable dyes as acid indicators, around 1670. Most of these dyes were already known as home medical remedies, such as syrup of violets. This link between medicine and chemistry was more common than we commonly imagine. Many early researchers in chemistry worked in pharmacies, or were professors of medicine. Boyle also published his knowledge that acids gave a flammable gas (now known as *hydrogen*) with some metals such as zinc and iron.

Nicholas Lemery (1645-1715) tried to explain (1680) how acids tasted sour by imagining that they had particles with points on them (fig. 3). This is a cause and effect explanation.

Lavoisier used his oxygen theory of acids to create a new nomenclature system with some of his fellow chemists (1787) to aid learning in a systematic way.

Davy, in 1810, showed that chlorine was an element, and that hydrochloric acid contained no oxygen. He created the idea that all acids contained hydrogen, but it took many years before textbooks adopted this. Wilson, writing in 1856, described two kinds of acids, oxoacids and hydracids.

Arrhenius, in 1884, put forward the thesis that acids form

Figure 3. A device used by Nicolas Lemery for the production of sulphuric acid per campanam.

hydrogen ions when in water, using electrical conductivity equipment invented for the new telegraph industry in 1840 by Kohlrausch.

The progression of ideas about acidity moved from a descriptive basis for a class of chemicals (the idea of an ideal or perfect acid), to a causal effect based on acids containing oxygen, then hydrogen. The idea that it was a component of the acid that made it acidic, changed when Arrhenius proposed that a new species, the hydrogen ion, was the cause of acidity.

Pedagogy

Discussions: inclusive discussions are common in English classrooms. However, good whole-class discussions may have interference from poor behaviour. Alternatively, well-structured group discussions may be more inclusive. Clear roles for group members need to be established through agreed ground rules.

Role play: good role play has clear direction concerning the roles, and sufficient time for the participants to think about their roles. A danger is that participants identify too much with their role. The teacher needs to give them time and space to step out of role, perhaps by an individual reflection activity about the other roles.

Teacher-generated plays. These were included in the student newspapers to provide evidence for the kind of discussions that were taking place at the time. Writing them at an appropriate literacy level was a challenge. One teacher-generated play on Boyle's use of indicators was used with significant success. A second play to discuss alternative views about acids, using a Galileo discourse style involving two attendees as one of Boyle's lectures, and a listening pie-seller, generated some valuable reflective discussion.

At the end of the lesson on ideal acids, they were shown a box containing a bottle of ideal acid. Opening the box, they saw the bottle was empty, because the ideal acid only exists in the imagination, it is not real. For homework, they created a box of their own with their learning about acids and ideal acid on the outside.

We were interested in whether the students could construct a chronology of discoveries about acids. This was done by a card sort where the random cards had to be placed in chronological order through discussion in small groups. This was not based on memory but on rational discussion. Most groups were able to do this.

Research evidence

The research evidence was collected by means of a word association test, student note-books, and field notes.

The word cloud below results from asking one class to record all the words they associated with *acid*. The responses ranged from 5 to 37 words. The text from all students was pasted into Wordle,[2] which outputs a word cloud, with the font size representing the frequency of use of the word. The word cloud demonstrates the largely negative view of *acid* by this group of students (fig. 4). The collection of words was made at the start of the module, and took 5 minutes.

One teacher was a graduate chemist, and the other was a graduate physicist. Both had been teachers for many years.

The lessons were quite short, 50 minutes with the usual delays in students arriving late from another lesson. This influenced time for discussions and scene-setting, and may have resulted in

Figure 4. Word cloud recording all the words associated with acid.

these sections being too short, in retrospect. Shorter lessons are becoming more common as head teachers try to squeeze more into the curriculum as a result of government interventions.

The lesson formats were influenced by pedagogical preferences of the two teachers, one taking a more socratic approach of question-answer sessions with the whole class, and the other giving more structured instructions for activity. In both cases, the students were following the lead of the teachers, limiting their own inquiries.

The shortage of time in each lesson, and pressures to complete the work in a short unit, led us to provide extra material in the form student newspapers. While we took every effort to make the reading as simple as possible, it remained a challenge for some of the students.

Dealing with younger students, who may lack maturity and skills to carry out activities required, put lots of pressure on simplifying the ideas.

The student boxes showed that the great majority understood the features of the ideal acid. My analysis suggests that a minority understood the nature of idealisation.

Reflections

There were a number of factors that influenced the study. Some of these were inevitable and out of control of the researcher, while others could be changed.

Since the teachers had expressed their view that their personal knowledge of HPS was limited, this provided a base for their work, such that the teachers saw this as a strong learning activity for them. In the first place, they claimed that they would simply enact the strategy in their classes but it was clear that local circumstances and their personality led them to adapt the programme.

Conclusion

I have described embedding HPS within a traditional framework for a sequence of lessons on acidity. I have provided evidence for this to be an effective alternative to engaging 11-14 year old students with this, otherwise dry, topic.

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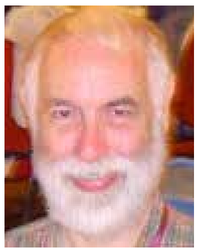

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[2] *http://www.wordle.net/* (last access: April 30th, 2013).