

A historical approach to teaching the concept of the chemical element

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An innovative teaching strategy helps 15-year-olds understand the idea of the chemical element

One of the key ideas of most basic chemistry curricula is the concept of the chemical element. However, experienced chemistry teachers know how difficult it is for young pupils to learn this concept.

In Portugal, the typical approach starts from the micro level (structure of matter, e.g. elements, molecules) and moves on to the macro level (behaviour of matter, e.g. physical and chemical changes, mass conservation). The basic assumption of such a pedagogical approach is that understanding of the macro level 'simply' involves a transfer of previously learned theoretical ideas, however abstract they might be. It is our contention that this is an unsatisfactory way of introducing basic chemistry concepts. No indirect evidence of the existence of the 'building blocks' (elements) is presented for the consideration of pupils. They are simply told that it exists.

ABSTRACT

A novel teaching strategy is described, which was developed to introduce the key notion of chemical elements to 15-year-old Portuguese chemistry pupils. The strategy started from the analysis of the so-called 'Lavoisier law' and explored the relationships between macro and micro level chemistry in an innovative way. The key idea was first to explore the macro level (mass conservation) to help pupils consider the existence of indestructible units (elements, micro level) as a logical necessity for making sense of experimentally observed phenomena. The approach facilitates the integration of content and process aims.

Since the 1980s, several authors (e.g. Anderson, 1986; Abraham, Williamson and Westbrook, 1994) have pointed out the conceptual difficulties that young pupils have in understanding the chemical element concept and, consequently, the related chemistry topics. For example, because of the difficulty of relating theoretical ideas (about elements) to the chemical symbols in equations, writing chemical equations often becomes a sort of mathematical game, with symbols to be added together on both sides of an imaginary equals sign. Many pupils can carry out the routine exercise of equation balancing, but lack the conceptual understanding of the nature of matter and of the changes represented by the chemical equations.

A strategy centred on the context of discovery

Justi and Gilbert (1999) state that science is usually presented as a collection of context-independent 'agreed upon facts' and pupils memorise the specific facts presented to them without questioning their development. Several authors advocate the introduction of the history and philosophy of science into science education as a possible way of highlighting its concern not only with the products, but also with the processes of the development of science ideas (Monk and Osborne, 1997; Irwin, 2000). We have explored this latter approach in the context of the so-called 'Lavoisier law' of conservation of mass and Lavoisier's well-known statement, '*nothing is created, neither in the operations of art nor in those of nature,*

and we may consider it a principle that, in every operation, there is an equal quantity of matter, before and after the operation; that the quality and quantity of the principles is the same, and that nothing more than changes and modifications occur' (translated from Lavoisier, 1864: 101).

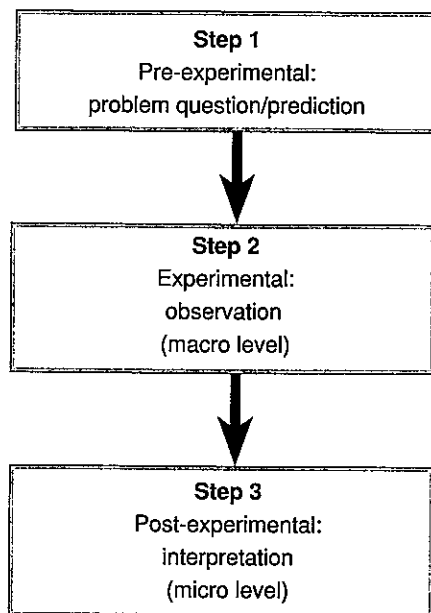
This statement contains the double idea of the conservation of mass (which Lavoisier determined with quite sophisticated balances) and the conservation of quality (elements), or rather, that mass is conserved because the elements are conserved. This implies the assumption of the existence of indestructible units in chemical reactions, an influential notion already well developed by Robert Boyle in the seventeenth century (Partington, 1961). This does not mean that Boyle's idea of 'element' coincides with the modern idea of element. As David Knight (1992) says, 'Boyle believed that the corpuscles (a term chosen for its lack of overtones) were arranged into stable "primary mixts" such as the metals: these would be something like our chemical elements, though to Boyle they seemed more like what modern chemists would call radicals' (p. 37).

The historic arguments developed by these two eminent chemists suggest an alternative approach to teaching the concept of the chemical element to young pupils, in which the interconnection between the macro and the micro levels is explored in a quite different way.

The proposed strategy

The basic idea is first to explore the macro level (mass conservation), in order to help pupils to consider the existence of indestructible units (e.g. elements, micro level) as a logical necessity to make sense of experimentally observed phenomena. Thus the goal of the usual experiments (e.g. the reaction between lead nitrate and potassium iodide) used to verify quantitative aspects of mass conservation in chemical reactions is now changed. The new goal is more heuristic as its focus is now in the context of discovery and not in the context of justification (testing). It means that the notion of mass conservation is not the end of the experiment but the start of an enquiry process. The micro and the macro levels are now fully integrated and not detached as in the traditional approach.

The three-step teaching strategy can be schematically presented as follows:



Such a strategy was recently developed with two grade 9 (15-year-old) mixed-ability chemistry classes in Portugal (21 and 24 pupils, respectively) over two 45-minute teaching periods. We did not design it as a full-scale research project, but rather as a preliminary innovative approach exploring action research ideas. In our view, this kind of educational intervention is more suitable for classroom teachers. Details about each step and comments about their implementation are given below.

Step 1: Pre-experimental: problem question/prediction

The main question concerned the likelihood of mass conservation in chemical reactions (an analogy with mass conservation in physical changes such as changes of state was explored). The teacher also asked for possible predictions from pupils about how mass conservation might be experimentally corroborated (comments were registered in an informal way to be explored afterwards).

Step 2: Experimental: Observation

The choice by the teacher of an appropriate example of a chemical reaction to explore mass conservation is crucial. In our case, the example chosen was the reaction between lead nitrate and potassium iodide solutions. The yellow precipitate (lead iodide) is easily recognised by pupils as an operational indicator that a chemical reaction has taken place. Understanding

that mass conservation takes place is an important prerequisite for the next step and may easily be understood at a phenomenological level (using a balance to measure the mass of the reactants and the products before and after the reaction). Therefore, it is not a problematic concept to learn at that level of abstraction provided the reaction takes place in a closed system (e.g. a conical flask).

Step 3: Post-experimental: Interpretation

This is the heuristic step. The basic idea explored was the need for pupils to consider the existence of indestructible entities, before and after the reaction, as a logical necessity to explain how qualitative changes (yellow precipitate) may be reconciled with mass conservation as observed in step 2. Thus, the idea of conservation of the element develops. As expected, this was the most problematic step. For example, some pupils assumed a kind of mechanistic model:

Teacher: *How do you explain that a yellow precipitate was formed?*

Pupil: *When we mix these two [solutions] this one [lead nitrate solution] binds to the other [potassium iodide solution].*

T: *If they were simply bound how is it that two colourless solutions produced a yellow one?*

P: *I don't really know.*

Some others students seemed to assume the existence of 'building blocks', for example:

P: *Some stuff must be kept the same ... the mass is equal.*

T: *What kind of stuff?*

P: *The particles ... I don't know the name.*

However, they found it quite difficult, at first, to understand that during the reaction these 'building blocks' must be reorganised (at this age level the idea of chemical change is simply explained in terms of separation/reorganisation of atoms). The use of models of atoms helped to overcome this difficulty and to structure pupils' learning. Similarities and differences between physical changes and chemical reactions were then explored.

Conclusion

Critical analysis of the history of an important chemistry principle was the starting point of this innovative teaching strategy to introduce the idea of a chemical element to 15-year-old Portuguese science pupils. Although this was only a preliminary study, we are optimistic about the potential educational relevance of the strategy. Both teachers involved considered that the strategy helped their pupils to *understand* chemistry rather than simply to *memorise* facts.

Chemistry is an experimental science and its experimental character should be explored as much as possible in teaching. The strategy followed makes it easier to integrate content and process aims. It also helps pupils to build up a more realistic image of chemistry and of how chemical knowledge is constructed. Teachers may also find it appropriate to propose a small project centred on the history of chemistry in order to enlarge the interpretation of chemical reactions, such as searching the Internet for information about the differences between the phlogiston theory and Lavoisier's combustion theory.

Finally, we believe strongly that successful use of this strategy depends on our ability to support chemistry teachers to look at the traditional school curriculum from a different angle.

Acknowledgement

We acknowledge the financial support of POCTI, FCT/Portugal.

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