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Parallels between Adolescents' Conception of Gases and the History of Chemistry

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Educational psychology suggests that the teaching and learning of scientific material is greatly enhanced if the students' pre-existing conceptual scheme is considered when pedagogic strategy is planned. Therefore, one of the most important lines of didactic investigation is that which addresses the diagnosis of previous knowledge (*1*, *2*) and the establishment of a theory for the teaching of science as a conceptual change (*3*, *4*) or even a change in both concepts and methodology (*5*).

The elementary teaching of chemistry in Spain begins at age 12 or 13 with an introduction to atomic structure, but too often the atomic explanation of solid, liquid, and gaseous properties is begun without an appreciation of the notions that students already have about these subjects.

Adolescents' Concepts of Gases

The problem under consideration is: what are the pre-existing concepts of adolescents about gases as material substances (especially with regard to the possession of mass), and how are these concepts modified in the minds of students who have completed basic and secondary studies?

One of the modern trends in educational psychology is derived from the hypothesis of "genetic epistemology" (*6*), that the learning of scientific concepts by a student often parallels the historical development of the science. This has been shown to be the case in mechanics (*7*, *8*). This essentially Piagetian hypothesis will provide the framework for our comparison between the concepts of gases and the history of chemistry.

According to Kuhn (*9*) the birth of chemistry as a science was due to two factors: development of the chemistry of gases and the appreciation of weight relationships in chemical reactions. This breakthrough was made possible by the understanding that gases are material substances that have weight, and since they have mass they can participate in such chemical processes as the oxidation of metal or the combustion of organic substances. Before gases were understood as material substances, it was not possible to establish the conservation of mass in chemical changes, especially in those cases when a detectable appearance or disappearance of solid and liquid material occurs (*11*, *12*).

The relationship between conservation of mass and atomism is a traditional epistemological subject. Children aged 9 or 10 have assimilated the idea of the conservation of substance but object to the invariance of weight in processes of form variation (*13*). Later, when they are 10 or 11, they understand the conservation of weight (*14*). Piaget (*15*) demonstrated the importance of the context in which these questions are addressed, showing that the results are not the same when the experiment presented involves a drastic decrease in the material perceived, as in the case of vaporization. That is, while they think that gas is "something" (substance), when treating the weight of gases, an Aristotelian conception of it is used. In this frame of reference, to have weight is equated with "to tend to fall" and consequently gases, which are the archetype of something that rises, have no weight and therefore no mass (*16*). To sum up, the equivalence for a child between gases and floating has the logical result that nonconservation of weight is expected when a solid or liquid turns into a gas, even in a hermetic container. The same thing will result when one asks about weight or mass measured with a balance. Because gases rise, neither weight nor mass need be conserved.

Our first hypothesis is that adolescents' preconceptions about the nature of gases will lead to significantly different abilities to rationalize conservation of quantity of substance as compared to conservation of mass, in processes where solids or liquids are transformed into gases. We also expect that since adolescents' conceptual schemes do not consider gases to have substance, they will have difficulties with the very idea of conservation of the quantity of substance. In fact, recent investigations have shown that many children aged 11 to 13 believe that air pressure is created only by wind, and it is difficult for them to understand that immobile air exists and acts (*17*). Also, Meheut (*18*) concludes from his tests that subjects accepted the idea that atoms of combusted material are permanent, but that they did not consider the role of oxygen as a material substance which takes part in these processes. These "nonmaterial" conceptions of gases in children aged 12 or less would correspond to those of a historical period prior to the 17th century; they also help to explain conceptual errors in treating gases (*19*) and aid in comprehension of elemental kinetic theory of gases observed by some investigators (*20*, *21*). Supportive of this idea is the work of Osborne and Cosgrove (*22*), who, in questioning 43 children about the change of state in boiling water, found that about 50% of them reply that the bubbles are of "air", the same answer that Aristotle would have given. In somewhat older children, we will find that their ideas correspond to the early period of pneumatic chemistry, where gases are recognized as substances but their chemical nature is not appreciated.

As a consequence of these adolescents' conceptual schemes, we can express a second hypothesis that, due to the persistence of the Aristotelian conception of the weight of gases, we must anticipate difficulties in the acceptance of the

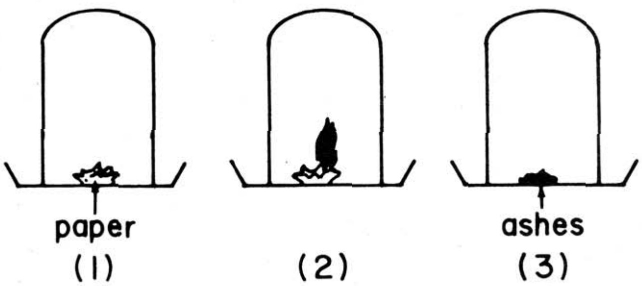

Figure 1. Item 8 asked pupils about the conservation of weight in the combustion of paper.

In picture 1, a piece of paper is put into the bell. In picture 2, we set fire to the paper and ashes are obtained in picture 3. If everything has been weighed (the bell, the dish and the substances) in each case, we would observe that:

a. Case 1 would have the larger weight.
b. Case 2 would have the larger weight.
c. Case 3 would have the larger weight.
d. A different answer.

Explain.

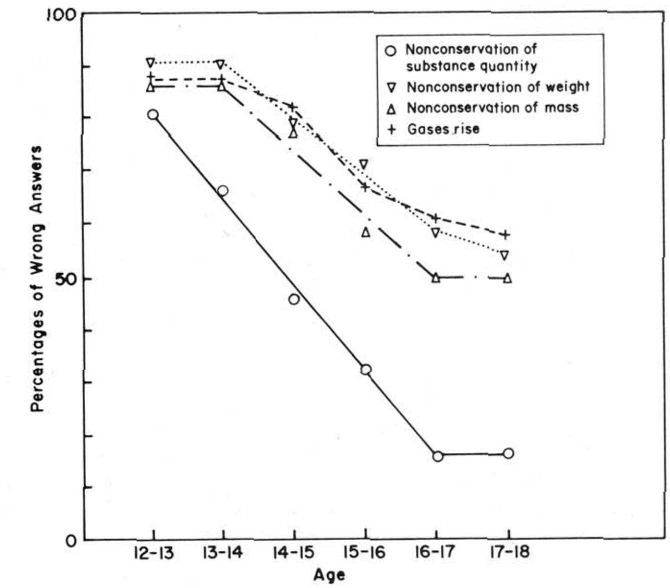

Figure 2. Gases are substances without weight that rise.

principle of conservation of weight or mass in those processes where corporeal material is converted into gases. Furthermore, we expect these difficulties will be most severe when the percentage of mass converted is largest, as in vaporization and combustion.

The justification for testing these hypotheses is associated with the inefficiency of the way in which the sciences and chemistry in particular are usually taught: as if the student were a *tabula rasa* where information can be written (*23, 24*). Consequently, it is not surprising that pupils' pre-existent conceptual framework remains unchanged, even after having seen the same material several times.

Experimental Design

Having stated the hypotheses above, we are going to examine them, building on experience obtained in a previous study (*25*). We prepared a simple test consisting of two questionnaires of four questions each. This test was administered at 12 schools to 1198 pupils of various socioeconomic levels in the province of Valencia. The pupils ranged in age from 12 years (7th EGB) to 17 or 18 years, pre-university (COU). Every student in the oldest two groups had studied physics and chemistry as an elective subject.

Questionnaire 1 included four items about an experiment involving the total vaporization of a liquid in a hermetically sealed container. We asked about conservation of substance (item 1), of weight (item 2) and of mass (item 3). (In this latter case, the word "mass" was substituted by drawings in which options with balances were shown.) Item 4 pretended to verify the conception of gas as "something that rises" out of a liquid that is boiled.

Questionnaire 2 had another four items in which the pupil was asked to predict what would happen to the weight of various substances in a number of common chemical processes, which included the apparent disappearance of material due to the involvement of gases. This is similar to the test about conservation of weight used by Piaget and Inhelder. The other three items referred to the dissolution in water of an effervescent aspirin (item 6), the oxidation of iron (item 7), and the combustion of paper inside a bell jar (item 8). Also included in this qualitative test was the vaporization of liquid (item 2), which had been asked previously. To be able to reference the responses, the solution of sugar in milk was chosen as a control test (item 5). As a sample of the questions, item 8 of this questionnaire is included here (Fig. 1). In general, the students had no difficulty in understanding the questions because of the pictures used. The questionnaires were administered under normal class conditions, without previous warning.

Results

The results of questionnaire 1 are stated in Table 1 and are graphically depicted in Figure 2. The percentages of wrong answers for items 2–4 (which refer to the conservation of weight and mass and gases rising) are quite similar within a given age group. On the average, there is a significant difference between the results obtained for items 2–4 and those for item 1, which refers to the conservation of quantity of substance. That is, even when the students came to perceive the idea of conservation of substances, they continued to err regarding the implication this has for weight and mass conservation.

Table 1. Percentages of Wrong Answers to Questionnaire 1

Course Age Number of pupils	7th EGB 12–13 224	8th EGB 13–14 175	1st BUP 14–15 251	2nd BUP 15–16 138	3rd BUP 16–17 211	COU 17–18 199	Total 1198
Substance conservation (Item 1)	81	66	46	32	16	17	43
Weight conservation (Item 2)	91	90	79	71	58	54	74
Mass conservation (Item 3)	86	87	77	58	49	51	69
"Gases rise" *(Item 4)*	88	86	82	67	61	58	74

Table 2. Percentages of Wrong Answers to Questionnaire 2

Course Age Number of pupils	7th EGB 12–13 224	8th EGB 13–14 175	1st BUP 14–15 251	2nd BUP 15–16 138	3rd BUP 16–17 211	COU 17–18 199	Total 1198
Solution of sugar in milk (Item 5)	49	34	42	23	23	19	32
Solution an effervescent aspirine (Item 6)	67	50	65	44	35	33	50
Oxidation of iron (Item 7)	78	73	65	39	35	32	55
Combustion of paper (Item 8)	81	86	77	67	47	44	67
Vaporization of liquid (Item 2)	91	90	79	71	56	54	74

Statistical analysis (chi-square method) of the results indicate that, in every age group, there is a significant difference in the fraction of students who understand conservation of weight as compared to the fraction who understand conservation of substance.

Our first hypothesis is proved by these results. Adolescent defenders of a "chemistry of common sense" would support the notion that gases are substances that, in comparison with the liquid they come from, have lost mass and weight and this is the reason why they rise.

The results found in questionnaire 2 are consistent with our second hypothesis. In Table 2 we have given the percentages of wrong answers on the conservation of weight in the five processes mentioned before. One can also find a large correlation of the percentage of wrong answers with the amount of material transformed to gases. As the perceptible amount of material in the process diminishes, the nonconservation of weight increases dramatically. Taking as a reference process the conservative Piagetian one (item 5), it can be observed that the difference between vaporization and item 5 is more or less 40%.

Briefly, the results found in these five processes show us that, in spite of having studied the atomic theory, our pupils in the secondary level largely do not use the principle of conservation of mass in processes in which gases take part and that this is due to their preconceptions. The more solid or liquid is gasified, the less conservative the students' answers will be.

Conclusions

We have shown in this study that the existence and persistence of adolescents' preconceptions about the material nature of gases is an important factor to be considered in the teaching of principles of conservation of substance, mass, and weight. These preconceptions, which resemble Aristotelian notions about the nature of gases, have a strong tendency to persist, even in students who have seen the atomistic conception of material presented several times. We have shown that three of four adolescents do not accept the principle of conservation of mass when gases are reagents or products, after having been taught by methods that ignore the pupils' preconceptions.

These results explain the difficulties experienced by children and adolescents with the concept of gases, for example, the finding that only 20% of English pupils aged 15 could correctly use the kinetic theory of gases in the interpretation of ordinary phenomena (*26*) or that French pupils aged 11 and 12 do not consider the participation of oxygen in combustion reactions (*18*).

Implications for the Teaching of Chemistry

The pupils' previous knowledge has a great influence on the process of learning (*24*) and not only affects the interpretation of phenomena but also sometimes makes the subject incomprehensible (*27*). In the study of chemistry, pupils' previous ideas on the interpretation of physical chemical transformations must be taken into account (*26*). A first prerequisite in these studies will be to overcome the notion that gases are substances "without weight", and recognizing this, to devise strategies to make the conceptual change necessary for a fundamental understanding of phenomena involving gases (*3, 28*).

We intend to pursue this line of investigation by attempting to create teaching materials adequate to change the Aristotelian conception of gases to the atomic one. If the material nature of gases is accepted by our pupils, they will be able to understand the principle of conservation of mass in physical–chemical processes, and we feel that, as was the case in the history of science, the role of gases is a key to the appreciation of the atomic theory of material.

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