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Making the Invisible Visible: A Constructivist Approach to the Experimental Teaching of Energy Changes in Chemical Systems

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THE PROBLEM

The subject "energy of chemical reactions" has been referred/reported as a theme in which the students demonstrate several difficulties of an adequate understanding (Johnstone, 1980; Finley, Stewart and Yarroch, 1982; Granville, 1985; Lawrenz, 1987; Shaibu, 1988). Some alternative conceptions in this area have been identified and are discribed (Cachapuz and Martins, 1987; Martins, 1989). For example, high school students may think that in some chemical reactions one of the reactants may play a more important role than the other(s), the so called "principal reactant" (PR) (Cachapuz and Martins, 1988). The idea of "principal reactant" is probably a specific case of a more general difficulty on the part of students in perceiving a chemical system in its entirety and it may be considered as a contemporary version of the duality between the sulphur and mercury principles used by 13th century Alchemists to explain natural phenomena. As referred by historians of science (Caron and Hutin, 1964) the sulphur principle would explain the active and warm properties of materials (hence the idea of "principal reactant") whereas the mercury principle would explain passive and cold attributes.

Of particular interest to this study is the Alchemists' interpretation of "combustibleness" in terms of the sulphur principle as" … the sulphur corresponded to the properties of the bodies which may burn…" (Vidal, 1986, p. 24). Thus the active or passive role played by a given substance in a combustion was probably associated to its perceptual salience. This argument is full of educational implications. This might well be the case of several combustions and of reactions between alkali metals and water both of which are an important part of the secondary chemistry curriculum in Portugal and in several countries. The flame usually produced in both reactions is probably a highly salient aspect (perceptual focus) and it may be hypothesized that in the absence of a formal model for the nature of energy changes in chemical systems, pupils may adopt an Alchemist-like view point. In this case one might antecipate that pupils may perceive the combustible material or the alkali metal as the "principal reactant". The flame would probably be perceived as a property of a reactant and not as the result of the reaction itself. Thus pupils would completely misrepresent the way energy changes in chemical systems take place.

Examples of experimental situations of the type referred to above are often selected by teachers. Probably, many of them have as choice criterion aspects of spectacularity of the task supposed to be more motivating for the student and, in this way more adequate to catch his/her attention. We have good reasons to think that many teachers are not fully aware of the educational implications this has in terms of students' learning. This may explain why some of the difficulties referred to above may persist even at college level. In fact, according to the generative learning model (Osborne and Wittrock, 1983) the construction of meaning from a given experience (for example, the observation of an experimental task) does not take place following empiricist views, but results, among other factors, from the interaction between the student's knowledge and the structure of the task itself. Thus, in the absence of an appropriate conceptual model for interpreting the chemical system under study, it is possible that the perceptual salience of the task's format plays a more important role in the selection of the information considered as relevant (for example, the chemical system's nature and its limits).

GOALS

The study aimed:

(i) To investigate high school students' ideas about "principal reactant" and its implications in the understanding of the energy changes associated with the reaction between sodium and water.

(ii) To analyse the persistence of the idea of "principal reactant" in chemistry college students when interpreting the combustion of magnesium.

(iii) To help teachers to be aware of educational implications of experimental tasks in which one of the reactants is at a more perceptual level than the other.

METHOD

Two samples of students were used:

(i) The high school student group (N=30) was formed by 15 subjects from grade 9 (average age 15) and 15 subjects from grade 11 (average age 17). These students were randomly selected from an initial group of volunteers drawn from mix ability classes of a high school located in an urban area of Portugal.

(ii) The college student group (N=29) was formed by subjects in their final year of a chemistry degree (5 year course). The students were drawn from two portuguese universities and all were volunteers.

The research method consisted of in-depth individual semi-structured interviews following demonstration of the experimental situation. No time limit was set. Students were requested to explain the situations. The interviews were taperecorded and later transcribed in written protocols and content analysis, closely following the method proposed by Erickson (1979).

RESULTS

(i) The reaction between sodium and water.

After a small piece of sodium is placed in a vessel containing water, it can be seen that the sodium darts across the water surface, smoke is released, and once in a while a yellowish flame appears next to the sodium. The sodium gets smaller and smaller until it completely vanishes. The temperature of the remaining solution is higher than the temperature of the water at the begining. High school students were invited to answer the questions: "How does the reaction take place?" "Why does the temperature increase?" "What is the origin of the flame?"

The main "model" used by students to explain energy changes involves the idea of "principal reactant" (PR) (Table 1).

Table 1. High school students' responses (%)

Students' Ideas	Grade 9	(N=15)	Grade 11	(N=15)
Adequate answer	0		0	
Principle reactant	(N=14)	93.3	(N=6)	40.0
Others	(N=1)	6.7	(N=9)	60.0

The flame observed in the reaction between sodium and water is one of the phenomenological aspects of the task , together with the movement of the piece of sodium, that causes more astonishment in the pupils. Probably because of this these aspects are highlighted by the textbooks and also by teachers (when the reaction occurs without flame, the teacher, normaly, repeats the experiment).

In the present study two thirds of the students interpreted the origin of the flame based on phenomenological aspects (and, for many of them, associated with common-sense knowledge). Therefore, the flame resulted from a combustion reaction -- the sodium combustion (the sodium was the reactant they saw desappearing) or from the energy released (generally evolved by the sodium). Two kinds of justifications were used by students, each one of them reflecting the idea of sodium as the "principal reactant".

a) A model of spontaneous energy transfer from the sodium to the water involving the non-discrimination between energy and temperature. When students were asked why the temperature of the solution rises, typical answers were: "…the sodium gives out energy and the water takes in that energy… it becomes hotter…". Students probably thought that it was the sodium that was burned out, and usually associated the process of energy changes with perceptual aspects of the task. For example: "…there was a flame when the sodium touched the water and that flame is energy which is being evolved (from the sodium)"; …"there was a light that evolved from the sodium".

b) A model of induced energy transfer from the sodium to the water. This was a slightly less popular model and probably reflects the need of a causal agent to explain why spontaneous reactions take place. In this case the energy of the water would play, in some way, the role of an "activation energy" in order to start the reaction: "… I think the sodium absorbs some energy from the water and then this energy is compensated by the sodium… it gives energy to the water… this is more than the energy it received from the water".

(ii) The combustion of magnesium.

Chemistry college students were invited to answer the question:
"How does the combustion of a magnesium ribbon take place by simply igniting it at one of its ends with the help of a match?"

This combustion is widely used in portuguese secondary schools since grade 8 (14 year - old pupils).

Table 2. College chemistry students' responses (%)

Students' ideas	Responses (%)
Adequate answer	(N=2) 6.9
Flame of the match is transferred to the ribbon	(N=7) 24.1
Others	(N=16) 55.2
No answer / don't know	(N=4) 13.8

Only two students gave the correct answer to the question. For 24.1% of them the evolution of the combustion reaction would require the use of successive amounts of an energetic component (for example, the match flame) given initially to the reactant system, which would be then transferred along the system to keep the reaction going (and not as a result of the evolution of the chemical system itself). This conception would imply a substantialist notion of energy (of the initiator agent) and a lack of comprehension of the role of ΔH in keeping the system with enough thermal energy. Its use would probably be highlighted in the case of the combustion of metals because of the salience of contextual factors (use of "conduction-type models" to interpret energy transfer along the system).

It seems important to note that seven of the 27 students that didn't answer adequately, don't refer the oxygen as one of the components of the reactant system. For these students the magnesium would probably be the principal reactant. This association of ideas was particularly salient in the case of the "flame transferred-model". For example: "… first the atoms in the ribbon receive the energy, and then they transfer it to the neighbouring atoms which then can react…" (the oxygen is not mentioned and the idea is that the reaction involves only magnesium atoms and the match flame).

CONCLUSIONS

The adequate understanding of energy of chemical reactions implies the acknowledgement of the chemical system, reactants and products, as a whole, and an articulate interaction between them. This is an essential prerequisite for the understanding of the concept of energetic balance. The difficulty of recognizing the totality of the reaction system in this way, may eventualy depend on the non-diferentiation between products

system and final chemical system. Moreover the observable modifications of the chemical system during the chemical reaction (as in the case of heterogenous initial systems) would perhaps reinforce the importance of the reactants (or one of them, in particular). The results suggest that a substantial number of students (both high school and college chemistry students) were not able to use a formal model to explain energy changes in chemical systems. In particular they evidence the idea of "principal reactant".

Teachers should be aware that for chemical systems in which one of the reactants is at a more salient perceptual level than the other, the former may be perceived as the more important reactant. This is often the case of solid/gas or solid/liquid heterogeneous (initial) systems in which the gas is not perceived, or when the liquid does not undergo any visible changes. In these cases perceptual focus on the solid is likely to take place. So, in the reaction between sodium and water, the fact that sodium is seen as desappearing and the water as conserving its aspect in the final system, probably suggests a more active role for the former and a more passive one for the latter, in the origin of the energy released. Also de positioning of the flame near the sodium would reinforce the idea that it results from the combustion of the sodium itself. To minimize this effect in the case of the reaction between sodium and water, it may help to use a piece of paper under the sodium (no flame is produced before the water is seen to spread out through the paper).

It seems very important to dedicate particular attention, during teaching, to the study of chemical reactions involving flame display, because the students could impute the origin of the reaction to the flame. In other words, the students could think that the flame observed during the reaction is not a consequence of the reaction itself but it is the initiator agent (match flame) which was transferred to the system (or to one of its components), such as in the case of the magnesium ribbon combustion.

A suggestion could be made here that teachers must carefully analyse the curriculum and textbooks in order to point out such reaction examples. It seems also particularly important to consider the experimental conditions in which experiments are to be demonstrated. Indeed, the task format is one of the more relevant aspects for teachers who want to influence the course of conceptual change in their students.

The approaches to chemistry teaching implied by the study described here may require teachers themselves to be aware of their role as teachers and to develop a new repertoire of strategies.

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