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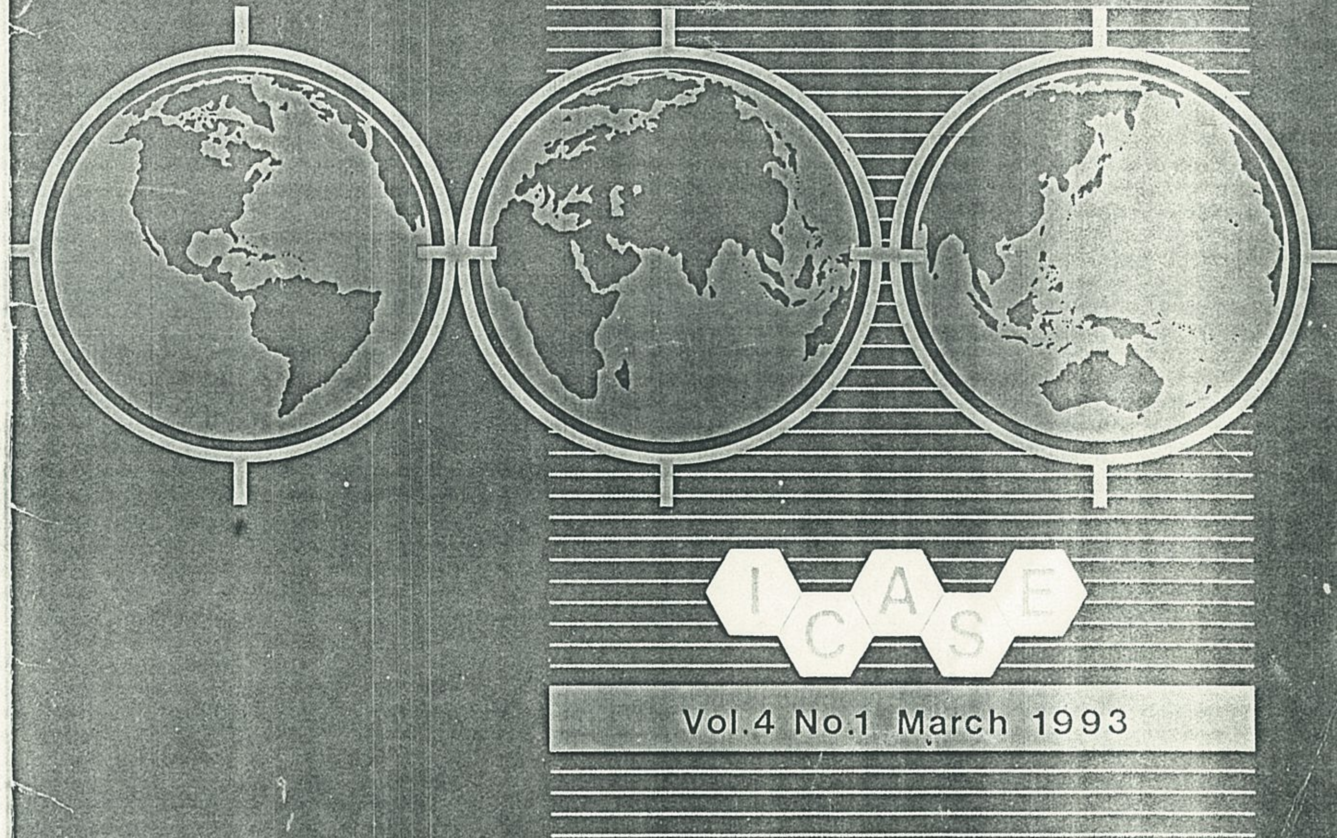

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Looking at science experiments through the students' eyes

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Introduction

A key feature of a constructivist approach to science teaching is that we must understand better the tasks which students are engaging and not just the tasks the teachers think they are giving (Posner, 1982). This requires a careful scrutiny and restructuring of course materials, in particular conventional examples and activities proposed to illustrate central concepts of the discipline. Such a critical analysis should be primarily based on research evidence. According to Driver and Oldham (1986) curriculum development from a constructivist perspective has to incorporate an 'empirical reflexive approach' (p 112). For example, teachers should be aware of potential problems raised by experiments used to illustrate the concept of chemical change in which the salience of phenomenological aspects of the experiment may induce perceptual dominant reasoning rather than conceptual dominant reasoning. In other words they should be aware of experimental aspects which may or may not facilitate bridging the gap between empirical levels of knowledge and conceptual levels of knowledge. This seems well to be the case of boiling an egg, often referred to in Portugal middle school chemistry as a suitable example of chemical change (for details about egg chemistry see Grosser, 1983, 1984). This is because boiling an egg is simultaneously a familiar, cheap, safe and easy experiment to set up in the classroom. As Arthur Grosser puts it, 'in our folklore, the newlywed who can't cook is exceeded in domestic incompetence only by the toast burner' (1984, p4).

Generally students are asked to identify when a chemical reaction has taken place by macroscopic changes such as the evolution of a gas, temperature or colour changes. In the present case, because of the very nature of the system (namely the existence of a shell) no such changes are directly identifiable and the most tangible feature accompanying the reaction raw egg — boiled egg is the increased hardness of the latter. Thus it may be hypothesized that some pupils perceive the transformation simply in terms of a change of state taking place inside the shell so the semifluid raw egg (egg white is almost all water, 88%) is transformed into 'solid' hard boiled egg, the nature of the initial system being conserved. It should be noted that (provided the egg doesn't crack) another perceptible feature occurring during the heating process, ie air bubbles which escape through the shell, is compatible with a physical change (decrease of internal pressure).

> *Valuable insights on teaching and learning may be gained from research and it is the aim of this section to bring significant research information to the attention of science teachers, with a view to helping them in their important work.*

The goal of this paper is to investigate whether the process of boiling an egg was understood as physical change by a sample of grade 9 (15 years old) and grade 11 (17 years old) Portuguese students and to analyse whether the nature of inadequate conceptions held by students in the elementary course differed from those in the advanced course. All students had been exposed to formal instruction in the topic of chemical reactions but in no case did the teachers explore the example under study.

Insights from the analysis may help science teachers to look at this experiment through the students' eyes and provide them with useful cues on how to explore alternative ways of teaching.

Research Procedures

The design adopted involved two closely related steps. In step 1, 30 students (15 of each grade level) were individually interviewed in order to build up conceptual inventories (Erickson, 1979) about the process involved when boiling an egg. Interviews (40min) were based on an experimental task consisting of boiling an egg (without cracking) in a saucepan. Typical questions asked of the students were: 'What happens to the egg?' or 'Why does it become hard?'

In step 2, main conceptions identified in the interviews were used to design two true/false questions subsequently administered to a representative sample of 262 grade 9 students and 186 grade 11 students (drawn from mixed ability classes from schools located in urban areas of Portugal). The two items (see below) were false as no student in step 1 gave the acceptable answer previously defined by their chemistry teacher. Acceptable answers for grade 9 students considered that the process of boiling an egg involves separation/reorganization of atoms in the egg with new substances being formed in the boiled egg. Energy of the raw egg molecules and heat energy supplied during boiling are transformed so that energy of the molecules in the boiled egg is greater. For grade 11, teachers expected that students would be able to use a formal model of chemical reaction, ie bond breaking

TABLE 1

Percentage of Responses

True (T) and Don't Know (DK)

Item		Grade 9 N=262	Grade 11 N=186	Average N=448
A	(T)	66.2	49.7	59.3
	(DK)	10.0	10.7	10.3
B	(T)	56.5	62.9	59.2
	(DK)	21.8	11.3	17.4

takes place with energy absorption whereas bond making releases energy, the net energy balance being positive. Heating increases the average kinetic energy of molecules in the raw egg and part of this energy is transformed into potential (bonding) energy of new molecules in the boiled egg.

The questions

As you know, if you put an egg (in its shell) in a pan containing water and heat the pan until the water boils, the egg gets boiled after a few minutes. Please indicate (in the space provided) which of the following statements are true (T), false (F) or don't know (DK). If you consider all the items to be false please write your suggestion in 'Other'.

(A) When boiled, the egg becomes solid because as the size of the particles increases they come closer together. ( )

(B) When boiled, the egg becomes solid because the bonding forces between the particles in the raw egg increase. ( )

Other:.......................................

The questions were administered by the science teachers (nearly 10 min) and slight modifications were introduced after a pilot study (N=30) took place.

Results

Roughly 60% of the students (step 2) agree with explanations not involving modifications in the nature of the substances composing the initial system (raw egg) and therefore were consistent with an understanding of the chemical reaction, raw egg — boiled egg, in terms of a physical change. The extent of the inadequate ideas held by students in step 2 is presented in Table 1. The data shows that the two mechanistic models tested, ie molecular packing as a function of either particle size (item A) or increase of 'bonding' forces (item B) were held by pupils from both grade levels hence suggesting the persistence of these alternative ideas. For each grade level there was a substantial percentage of DK responses, specially for item B. Only a few answers were obtained for 'Other', some of which rendering problematic the content analysis.

(a) Molecular packing and particle size

In this case (item A) the process would involve a change in the size of individual particles themselves. Pupils probably transferred to the microscopic level knowledge of properties usually perceived at the macroscopic level (eg metals expand when they are heated) a tendency which has been acknowledged by some authors (Driver, 1985; Ben Zvi et al, 1986). Interview transcripts obtained in step 1 suggest that pupils' attempts to use models of particulate nature of matter were probably guided by perceptually dominant arguments of the kind: hard boiled egg (solid egg) — particles tighter — volume of the egg is the same — size of particles increases. For example:

... when we heat the egg the particles become bigger ... the size (of the particles) increases and they become tighter (in the boiled egg) ... you see the egg is now harder; it is more solid (grade 9)

Such local reasoning is consistent with ideas of conservation of substance described in the literature (Anderson, 1986; Méheut et al, 1985).

(b) Molecular packing and 'bonding' forces

Some pupils (item B) explained the reaction as a direct result of the heat energy transferred to the system. This transfer would increase the intensity of the bonding forces between the molecules in the raw egg so they become more packed. It should be noted that the nature of the particles would remain unchanged in both the raw egg and the boiled egg. This could imply some sort of packing at the microscopic level. Typical responses given in step 1 are illustrated by the following transcript:

... we heat the egg and it becomes solid ... when it's boiled the molecules are stronger; you know, the bonds between the molecules are stronger (grade 11)

This mechanistic model was slightly more sophisticated than the previous one (item A) as students were somehow able to appreciate, the role of intermolecular (though inadequate) attributes to explain the 'physical change'. This probably explains the positive shift observed for grade 11 students. These students were not able to appreciate the difference between force and energy and its implications at the intermolecular level.

This confusion, which has been reported in other contexts (Brook et al, 1984) seems to be an important barrier to proper understanding of the chemical change under study. In this case solids would have more energy than liquids (irrespective of temperature) simply because in the former particles are more packed, i.e. 'more packed' means 'more energy'. For example:

. . . this one (the boiled egg) takes in heat and it's harder . . . you see the energy between the atoms of the solid is greater than the energy of the liquid (Grade 11)

Thus the change liquid — solid would be compatible with an endothermic process.

Discussion

Although experiments are indispensable tools in chemistry teaching, there is a need to be more critical about the sort of experiments we use and how they are used. We should perhaps re-examine the criteria used to choose some experiments we use and how they are used. We should perhaps re-examine the criteria used to choose some experiments proposed to pupils in our teaching, in particular the ones which have a perceptually obvious focus of attention. Familiarity with an event may not be the main criteria to select experiments in science lessons when perceptual aspects of the task may overrule conceptual dominant reasoning.

Clearly teachers should be more aware of the nature and role played by alternative ideas held by students about chemical change, both in structural and energetic terms (Martins & Cachapuz, 1990). In this investigation it became apparent how inadequate ideas about structural arrangements in solids and liquids which were earlier introduced in junior high school influenced further understanding of a chemical reaction. These inadequate ideas may often be used in a consistent and logical (though incorrect) way and are usually quite resistant to change as illustrated in this report for students from grades 9 and 11. Alternative ideas such as those identified in this study reflect how meaning was constructed by students and thus may be explored as inputs to help teachers to design appropriate diagnostic questions. For example, to challenge the idea referred to above that 'the energy of solids would be greater than the energy of liquids', teachers may find it useful to discuss this argument with pupils when the white (of a broken egg) is frozen. Furthermore they may also discuss whether the term egg used to name both the initial and the final systems implies the idea of conservation of substance.

Since for middle school students egg chemistry is beyond their level of comprehension, teachers should base alternative explanations exploring differences between directly perceived properties in both the initial and final systems, namely taste. For grade 11 students, teachers may go a bit further and explore elementary aspects of egg chemistry. For example, they may explain why cooked eggs present sometimes a dark green deposit (iron sulfide) as a result of a chemical reaction between iron (from the yolk) and hydrogen sulfide formed when proteins in the white are decomposed by heating (rinsing with cold water prevents the formation of iron sulfide). This will help students to adequately contextualize the process of boiling an egg in chemistry terms and to establish useful content bridges with the Biology course.

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