A Burning Issue for Chemistry Teachers

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In the area of chemistry education the subject of burning continues to be a source of conceptual problems for many students of all ages. Research has shown that students' ideas on what is happening in a chemical reaction described as 'burning' or 'combustion' are many and varied, ranging from the assertion that in some cases (for example, metals) no chemical change takes place, through confusion of the role of oxygen in the reaction system, to difficulties in describing the energetics involved.

This paper reviews many of the misconceptions about burning reactions uncovered in recent research and discusses some of the underlying fundamental problems in students' understandings of the chemistry principles that lead to them. Some advice is offered to science teachers in helping students overcome their difficulties in this area.

Students' Misconceptions and Difficulties

Among the studies which have examined students' conceptions of combustion, before and after instruction, are Knox (1985), and Mehuet, Saltiel and Tiberghien (1985); both involving 11-12 year olds. Prior to instruction, the majority of students in both studies essentially used perceptual thinking (instead of conceptual thinking) and held what Driver (1985) deemed as 'prototypic' ideas about burning, i.e. burning involves a flame; products are smoke and an incombustible material known as the ash; the change is irreversible; and oxygen/air is needed, but its role is unclear or unknown. After specific instruction which includes the concept of interaction between oxygen and the combustible material, both studies reported that students are still unable to grasp the role of oxygen in combining chemically with the combustible material. Instead, they still show evidence of the use of perceptual thinking instead of conceptual thinking.

Further evidence of the use of perceptually dominated thinking in interpreting combustion reactions is reported by BouJaoude (1991) and Abraham et al. (1992); in both these studies the majority of the students studied see candle wax as merely melting and not burning.

Hesse and Anderson (1992) in a post-instruction study on older students (aged 16-19) also reported that the majority of the students use everyday or prototypic notions about burning instead of the scientific concepts.

Most of the studies on combustion include a concern with ideas of conservation of mass. This concept of conservation of mass is related to students' understandings of the concept of interaction between particles of reactants.

A written question about the burning of iron wool was given to the students in the Knox (1985) study mentioned earlier as well as to a group of 15-year-olds (n=765) as part of the APU survey (Driver et al., 1984). Results showed that only about 25% of both age groups predicted that the iron wool would become heavier after heating in air, and of these only a few gave the acceptable reason that oxygen from the air has combined with the iron. In the same survey with respect to a question about the rusting of iron, only about a third of the 15-year-old students predicted that the weight would increase, of whom only a minority gave the correct reason that oxygen from the air has combined with the nails to form the iron oxide or rust.

Likewise, 9 out of the 11 students (aged 15-17) in the Hesse and Anderson (1992) study also reached incorrect conclusions about the mass of the products formed in three separate reactions (rusting, burning of copper and burning of a wood splint) because they failed to understand the nature of the chemical interaction and hence the conservation of mass involved. Instead they used reasoning that is more appropriate for physical changes (such as regarding rusting as a sort of "change of state" of the iron; nothing was lost and nothing was gained.)

Ross (1991) reported a survey of people's views about burning in which no specific details were given of the nature of instrument used or the context or the sample involved other than that it included various groups of people such as firemen and people with strong science backgrounds. He reported that burning is often seen as destructive and that oxygen, if mentioned at all, is usually seen as a "helper" rather than as a reactant and flames are seen as the active agent of destruction instead of the result of chemical interaction between the combustible material and oxygen.

In a study of A-level students' conceptualisations of some common chemical reactions Boo (1994) identified the following misconceptions specifically associated with burning:

- In a number of cases, the everyday notions about burning co-existed with scientific views. For example, metals like copper can only melt (or form the oxide) but not be burned; only carbon containing compounds burn to release energy.
- Some students thought that burning can take place without oxygen - because the everyday understanding of the term burning as catching fire or application of heat was used.
- The role of oxygen in burning was not understood; oxygen was seen as playing a permissive or an active role.
- The similarity between the candle flame and bunsen flame was not recognised.
- Metals were thought to melt but not burn.
- Metals were thought to oxidise but not burn.
- Only carbon containing compounds were thought to be capable of burning.
- The candle wax in a burning candle was perceived as not to be burning but only melting.

The fact that such misconceptions were held by a group of students who had undergone several years of chemistry instruction, had chosen to specialise in Chemistry and, in many cases expected to go on to study chemistry or chemistry related subjects at universities supports the view of many researchers (eg Nussbaum and Novick, 1982; Gunstone, Champagne and Klopfer, 1981; Champagne et al, 1981; Moreira, 1987; Gunstone and White, 1981; Clough and Driver, 1985) that alternative conceptions are often robust and resistant to change despite teaching strategies specifically designed to address them.

Some Underlying Problems

Many of the difficulties described earlier can be traced back to one or more of a number of underlying problems that students appear to encounter in the learning of chemistry.

1. Some problems in students' conceptualisations of burning and combustion arise directly out of the differing use of terms in science and everyday language. Whilst 'burning' has a precise meaning to a chemist, in everyday language it is used to express a number of different ideas; for example, set alight, catching fire, destruction by fire, application of excess heat (eg sun-burn).

2. Since burning and combustion are so much a part of everyday life, many students' views on burning are dominated by everyday perceptual clues; for example, many students are unable to conceptualise the oxidation of copper as burning since there is no visible flame, many students regard candle wax as merely melting and not burning – the flame being attributed to the burning wick.

3. As pointed out by Brosnan (1992), some students hold the naive view of chemical change as involving an active agent acting upon a passive substance instead of involving equal partners in interaction. Because of this view, the role of oxygen is often misconceptualised: some students view oxygen as the active agent of change; yet others misconceive oxygen as merely a helper or facilitator of change.

4. Many studies (for example, Knox, 1985; Mehuet, Saltiel and Tiberghien, 1985; Bodner, 1991; Hesse and Anderson, 1992, Boo, 1994) have demonstrated the persistence of naive or erroneous conceptions amongst chemistry students, even up to graduate level, despite the inclusion of specific topics in course materials designed to overcome them.

5. The concept of fuels, for example hydrocarbons or food, as being 'energy-rich' (discussed by Ross, 1991) leads to many problems when students come to consider the energetics of the combustion reaction. This point is addressed in more detail in point (7) below.

6. Few students will consider all aspects of the reaction system. For example, even at A-level, Boo (1994) has observed that whilst most students will display a reasonable view of burning as involving some form of breaking down the combustible material and the reaction of these smaller parts with oxygen, few students will volunteer the necessary breaking of the O-O bond in the O_2 molecule as part of the reaction system.

7. At the same time, amongst this sample of students studied by Boo (1994), who had some exposure to the topic of chemical energetics, there is widespread misunderstanding of the energy changes that take place in, and are, the driving force of reaction systems. The concepts of entropy and enthalpy change are rarely volunteered by students and appear to be poorly appreciated. Many of these students came into chemistry with specific ideas about energy which appeared to be linked with what they had learnt in their physics courses (ideas such as "energy is the capacity to do work", which was often loosely interpreted as the ability to make things or to do things). Also, a common misconception, is that fuels and food are considered to be energy rich or stores of chemical energy and that energy is released by their combustion. These two apparently mutually supportive conjectures appear to lead many students into the trap of believing that the energy released during combustion comes from the combustible material alone, instead of from the fuel-oxygen reaction system as a whole. In other words, they believe that the breaking up of

the molecules of the combustible material into smaller fragments releases energy. This leads to the assertion that bond breaking releases energy (ie is exothermic) whilst bond making requires energy input (ie is endothermic).

8. These problems are further compounded by many teachers' lack of awareness of the existence of students' preconceptions, and of the nature of these preconceptions (such as their resistance to change by formal instruction and so forth).

Implications for Science Teaching

Burning is both a common everyday experience and a common type of reaction in the school science syllabus; if teachers can instill the correct concepts in students' minds in this area then it should, by extrapolation, lead to better understanding of the fundamental concept of chemical interaction which permeates the whole subject of chemistry.

It has been speculated in an earlier work (Boo, 1994) that with all misconceptions and misunderstandings, the longer they are held, the more firmly they are held and are thus more resistant to change by the teaching process. It is therefore most important that at each stage of concept development the teacher reviews the new level of understanding reached by students to check that both the teaching objectives (in terms of new understandings) have been achieved and to identify any new misconceptions that students may have generated though incomplete understanding. Implicit in this review mechanism is that, at the commencement of any course segment or module, the teacher must ascertain.the existing knowledge level and extent of initial misconceptions and be prepared to change the teaching strategy accordingly.

With regard to burning in particular, it is important to consider the logical order of concept introduction. For example, given the crucial role of oxygen in the reaction system, any consideration of burning should be preceded by at least an introductory study of oxygen. Once the role of oxygen as a reactant, not just an aid to burning, is appreciated then the issue of mass conservation can be more easily understood. A basic understanding that physical changes (for example, state changes) can co-exist with chemical changes might help prevent the common misconception that, for example, candle wax and metals only melt and do not burn. Consideration also needs to be given as to when and how to introduce the particulate model, itself a demanding concept for most students.

Care needs to be exercised in the use of language; students should be encouraged from a very early age to appreciate that in science many of the words which are used have a precise meaning which at best may be only a subset of the meanings encountered in everyday usage or at worst be quite different (think of a burning desire).

As students build up their store of scientific knowledge they must be encouraged to develop a process of multi-variable thinking and to consider a 'system' in its entirety. Many researchers (for example, Driver 1985; Boo 1994) have observed that many students consider only a very narrow subset of variables or constrain the boundaries of the 'system' under consideration when describing chemical events.

Throughout their science education, students should be encouraged to seek maximum generality of explanation for their conceptualisations and theories (for an in-depth discussion of this topic the reader is referred to Reif and Larkin, 1991). Because of this lack of ability to generalise and take the scientists view of many similar events as being multiple manifestation of the same underlying principle, many students have been observed (for example by BouJaoude, 1991; Boo 1994) to view events within narrow, task specific, boundaries thus leading the burning candle and the bunsen flame to be perceived as very different types of chemical reaction.

At more advanced levels it is vital that students not only learn the basic rules of chemical energetics but understand how to apply them to real reaction systems since this forms the basis of much of the predictive nature of chemical knowledge.

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