CITATION Palmer, W. P. (1989). Some thoughts on Teaching Changes of State and Chemical Change. Paper presented at CONSTANT 12 (Annual Meeting of the Science Teachers' Association of the Northern Territory, held at Katherine, N.T. 22-24 September.

SOME THOUGHTS ON TEACHING CHANGES OF STATE AND CHEMICAL CHANGE

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PAPER PRESENTED TO

SCIENCE TEACHERS ASSOCIATION OF THE NORTHERN TERRITORY CONFERENCE "CONSTANT 12"

KATHERINE HIGH SCHOOL KATHERINE, NORTHERN TERRITORY

FROM 22 - 24 SEPTEMBER 1989

ABSTRACT

Chemical change is a central theme of Chemistry which has itself been called the central science. This was the title of a popular American text book. I am thus putting forward the idea that chemical change is an idea central to science as a whole, so that it would be one of the ideas children should understand clearly whilst at school. This is both because that understanding is important to handle chemistry at higher levels and also because in the world outside schools it is essential to the understanding of the great issues of our time.

The article goes on to consider methods of introducing the concept of physical and chemical change, comparing the differences between physical and chemical changes; it includes some literary and anecdotal evidence about physical and chemical change, children's science and other research about physical and chemical change, models of physical and chemical change and practical experiments to illustrate physical and chemical change.

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INTRODUCTION

Chemical change is a central theme of Chemistry which has itself been called the central science. This was the title of a popular American text book (Brown and Le May, 1981) and also of a series of essays on chemistry (Kauffman and Szmant, 1985). I am thus putting forward the idea that chemical change is an idea central to science as a whole, so that it would be one of the ideas children should understand clearly whilst at school. This is both because that understanding is important to handle chemistry at higher levels and also because in the world outside schools it is essential to the understanding of the great issues of our time. A stated grasp of the phrase 'chemical change' is seldom demanded in the media though recently I came across these words when reading the Weekend Australian {Barclay, 1989) 'Late in 1963 the clinic's Dr King told her that she was neither 100 per cent female nor 100 per cent male, that a chemical change had occurred in her body'.

By the way I would be grateful for any other instances of the phrase 'chemical change' occurring in the media: perhaps after its usage in *The Australian* the readers of *The Herald* and *The Sun* will also be similarly challenged!

More importantly and more frequently, when the media considers great scientific issues in a form comprehensible to the general public, the understanding of chemical change, which is necessary, is not stated specifically. For example environmental issues such as the greenhouse effect, the ozone layer, problems involved in mining, atmospheric pollution, the nuclear winter or human health issues such as AIDS, cancer and fluoride in the water supply etc.- all these need amongst other scientific knowledge, an understanding of chemical change. Moreover people often do not understand what chemical change means, so they will not be aware of how difficult it is to reverse some of these effects.

My conclusion is that it is important to teach chemical change thoroughly at school, but my talk is about the best way in which this could be achieved in practice.

PHYSICAL AND CHEMICAL CHANGE

Firstly I will try to see how chemical change has been taught at different periods in history and in different countries, choosing examples from some common text books. Historically our approach to understanding is by contrasting chemical change with physical change, and therefore being able to classify any change as either physical change (change of state) or chemical change. For example Hooton (1911, p37) gives examples of various changes and then states that 'It is not possible to draw a hard and fast line between chemical and physical changes. Sharp boundaries do not exist in nature; the classification is made merely for our own convenience'. Hooton has certainly realised some of the problems of the simple classification, physical change as opposed to chemical change. Nonetheless this classification appears in text.

Figure 1
COMPARISON OF PHYSICAL AND CHEMICAL CHANGES

PHYSICAL CHANGE	CHEMICAL CHANGE
No substance formed or destroyed.	Substances changed-New substances formed.
No change in weight.	Change in weight.
Reverse change easy.	Reverse change difficult.
No energy produced although energy may be changed from one form to another.	Energy in the form of light or heat may be given out as a result of chemical change.

The criteria given are somewhat misleading, particularly the change in weight (under chemical change), as this could be interpreted as disobeying the law of conservation of mass. Later in the next section I will quote evidence that this traditional contrast between physical and chemical change is decreasing in newer text books which may lessen the familiarity of today's students with chemical change. However I will now present some literary and anecdotal evidence for the way physical and chemical change have been taught in schools.

SOME LITERARY AND ANECDOTAL EVIDENCE
I find biography/autobiography an interesting revealing and sometimes humorous way of seeing the influence that school science had on the lives of real people as they remember it. The two extracts from Australian authors that I have chosen illustrate firstly the effect of violent chemical change as remembered by Clive James and secondly an incident where there were really only physical changes, recalled by Alan Marshall.

> I was coping with physics and chemistry well enough while Mr Ryan was still teaching them. But Mr Ryan was due for retirement, an event which was hastened by an accident in the laboratory. He was showing how careful you had to be when handling potassium in the presence of water. Certainly you had to be more careful then he was. The school's entire supply of potassium ignited at once. Wreathed by dense smoke and lit by garish flames, the stunned Mr Ryan looked like a superannuated Greek god in receipt of bad news. The smoke enveloped us all. Windows being thrown open, it jetted into what passed for a playground, where it hung around like some sinister leftover from a battle on the Somme. Shocked, scorched and gassed, Mr Ryan was carried way, never to return. (James, 1980)

> Once a week we were given a lesson called "Science". I liked this lesson because then we were allowed to stand round the table and you could push and shove and have fun. Mr Tucker opened the cupboard containing some glass tubes, a spirit lamp, a bottle of mercury and a leather disc with a piece of string attached to the centre. He placed these things on the table and said, "Today we are concerned with the weight of air which is fourteen pounds to the square inch".

> This didn't make sense to me but the fact that I was standing beside Maggie Mulligan made me wish to shine so I proffered the information that my father had told me the fuller you are with air the lighter you are and you couldn't sink in the river. I thought this had some bearing on the subject but Mr Tucker slowly put the piece of leather back on the table then looked at me with his eyes so that I could not face him and said through his teeth, "Marshall, I would have you know that we are not interested in your father or in any observation made by your

father even if such observations proclaim the stupidity of his son. Would you please attend to the lesson?"

He then wet the leather disc and pressed it on the desk and none of us could pull it off except Maggie Mulligan who ripped the guts out of it with one yank and proved air didn't weigh anything. She told me when she was wheeling me home that what I said was right and that air weighed nothing. (Marshall, 1979)

The two autobiographical extracts above appear to cast chemistry/science in a rather negative light. There is criticism too for science teaching from the UK (Satchell, 1982). Satchell, himself a chemist, wrote a letter complaining about the way his son was being taught chemistry, referring particularly to the old-fashioned text-book he was using. He criticised a number of basic definitions and the idea of physical and chemical change, such as that presented as in Figure 1, saying that 'these criteria do not bear serious examination! Why bother with them in books at this level?'

As a result of this letter and a number of letters reacting (exothermically) to it, I looked at how physical and chemical change were introduced in a number of UK, Australian and some English speaking Commonwealth countries (Palmer 1989). I observed that recent United Kingdom texts tend to talk about chemical reaction rather than chemical change, and change of state rather than physical change, and to deal with these topics in different sections of their books. UK texts, in general no longer oppose physical and chemical change though I found three recent texts that do this. Against the trend, one very recent British author (Atkins 1989, p.5) writing for the American market practically starts the book by defining physical and chemical change. Books from developing countries, with which I am familiar, tend to use the traditional approach of opposing physical and chemical change. In Australia eight books out of the nine I looked at followed the traditional approach.

To sum up, the U.K. approach is now to teach chemical reaction and change of state separately, whilst in Australia, physical and chemical change tend to be contrasted traditionally. Of course in either country what is found in text books may not represent practice in the classroom. At this stage the argument as to what does happen and to what should happen is inconclusive.

The next three sections of the paper will consider the results of recent research on children's understanding of physical and chemical change from different research perspectives.

CHILDREN'S SCIENCE RESEARCH

Tasker (1989, P 13) as a result of New Zealand research reveals that the mnemonic 'MRS GREN' is used by students to help remember how to differentiate between living and non living things. He states that 'not only have they (the students) thought that fire was living, but their teacher has told them that it is'. He further states that 'in my college typically in every group of twenty beginning teacher-trainees three or four classify fire as living'. This indicates both children and adults are unclear about the living/non living classification, and it also indicates that they are all unclear about exothermic chemical change.

Schollum & Happs (1982) asked children what they thought was happening in the following situations (a) the gases produced above a Bunsen burner (b) sugar being heated in a teaspoon (c) a candle burning. They contrast the children's views of what is happening against a correct scientific explanation, and thus show that children do not understand chemical change. For example children considered that no new substances were formed when substances burnt! This is a contradiction of the one definition of chemical change everyone agrees should be taught. The paper identifies the problems, but gives no clear message about the solution.

Osborne and Cosgrove (1983) looked at children's understanding of some common physical changes. They interviewed children about a number of common situations when liquid water vaporised or gaseous water condensed. The children varied in age between eight and seventeen years old. The type of explanation offered to a number of a multiple choice questions were broadly similar in each case. In one example a wet cup and saucer were allowed to dry and the children were asked where the water had gone. Possible explanations were: into the cup and saucer, it no longer exists, it exists as little bits in air or it had split up into hydrogen and oxygen. The percentage (up to 40% at some ages) who explained that the water split up into hydrogen and oxygen leaves no room for complacency that the children concerned understood either physical or chemical change. The only cause for comfort is that as the children became older numbers offering the correct scientific view increased, though this might only be reflecting the greater selectivity of the education system for the older age group.

SOME S.I.S.S. RESEARCH

The S.I.S.S. project (Rosier, 1987) (Rosier, 1988) and (Martin, 1988) gave the same science tests to groups of children of about the same ages in many countries around the world. The age groups/grades were grade 4/5, (population 1), grades 8/9 (population 2) and grade 12 (population 3). Tests were carried out between 1983 and 1986 after several years of prior planning. At the time I was a member of a committee organising and planning this research in P.N.G. Very large amounts of data were collected and at present only some preliminary results have been published (IEA, 1988)
In Papua New Guinea, which took part in the population 2 and population 3 tests, the overall picture of science education may be found in articles by Deutrom & Wilson (1986) and Wilson (1986). Some tentative findings are available in Palmer (1986 b) and Wilson (1989). My research focussed on the performance of secondary teachers who answered the population 2 tests immediately after the students they had been teaching had done the tests. The size of the sample was probably about half the total number of teachers teaching Grade 10, and there was no overall control over which teachers completed the tests or the circumstances under which they were completed. The results were really very good for most teachers, but the performance of some teachers indicated they themselves had trouble understanding some quite basic concepts. It is likely that some of those who answered only parts of the test (these results were ignored) and those who did not do the test at all may have been even weaker in their understanding of scientific concepts. Such teachers would be able to teach their students very little. A second point was that the teachers appeared to find chemistry questions most difficult and the biology and earth science questions least difficult. My own view is that this is a direct result of the very small amount of chemistry in the PNG Science syllabus. This situation has now been remedied at least in part.

Finally there was an analysis of individual questions which I think is perhaps where the S.I.S.S. survey can be of most practical value. The most difficult question on the test for the teachers was a chemistry one testing knowledge of the generalisation that 'the property of a compound is different from those of its constituent elements'. This idea, closely related to the meaning of chemical change, was not at all well understood. It is made even more interesting when comparing these results with earlier surveys. McKay (1968) tested G 10 PNG high school students. Later Boeha (1980) used the same general test on science for remedial students from the University of Technology, Lae. In both cases the same questions about chemical change caused the students the greatest difficulty. These could be freak results with apparent difficulty being due to the complex language of some of the questions, particularly for students learning in a second language. However, I think that there was enough evidence to indicate that more careful teaching of this area was needed. Similar conclusions have been reached elsewhere. Fensham (1988) reporting Mitchell's earlier work on ways to improve the teaching of stoichiometry. It is also instructive to note confirmatory evidence from the APU results.

APU RESEARCH

The Assessment of Performance Unit in the United Kingdom is a government funded research unit which attempts to monitor standards in major subject areas in UK schools. In science its monitoring work has been with 11 year olds, 13 year olds and 15 year olds as reported in DES (1981), DES (1982a) and DES (1982b).In a brief summary of its work on 15 year olds (APU 1985, p.13) which related to relatively straightforward concepts (including chemical change) they found that ‘about one third of all pupils would successfully apply them’.

A more recent article (Donnelly and Welford, 1988) examines the performance on these questions in greater detail splitting the population into five groups on the basis of general performance. One question asked candidates to recognise that burning paper to form smoke and ash was a chemical change. 70% of the high achievers recognised this, but for other groups the percentage understanding this varied between 29% and 9%. This is perhaps the most startling result, but similar results emerged considering other chemical principles. Taken at its face value this would indicate only about 20% of the children can understand the idea of chemical change: perhaps this is overstated, but Donnelly and Welford put it like this:-

> Only among the most able group did the majority identify burning as a chemical reaction, and the greatest shift in performance was between this group and the next. These figures are perhaps of concern. While the distinction between 'physical' and 'chemical' phenomena can be overdrawn it seems to be essential that pupils have a conception of chemical change which they can apply to simple cases such as those suggested here. Without it a more sophisticated understanding of chemic.al changes may prove inaccessible.

In conclusion they point out that:-

> Combustion is perhaps the archetypal chemical change, and the absence of a notion of 'chemical change' seems to underpin these difficulties and others observed in APU findings. Pupils, not unreasonably, identify even simple examples of chemical reactions with changes of state, physical breakdown and the removal of impurities. It seems unlikely that this can be improved by attention to formal definitions, however clearly or imaginatively presented.

SOME THEORETICAL ASPECTS

The evidence given so far indicates that children have difficulty with the idea of change of state and chemical change. Can educational psychology help in clarifying where student difficulties lie?

Ausubel's dictum (Ausubel, 1968) is ‘Ascertain what the learner already knows and teach accordingly’. The last three sections of this paper have in their various ways tried to find out what the children know, but the second part of the dictum remains problematic.

It might help to construct a concept map (White, 1988) (Hegarty 1984) or a concept inventory (Tamir, 1984). In fact Gower, Daniels and Lloyd (1977, p.286) constructed such a concept map for empirical (experimentally derived) concepts. Their hierarchy has matter as its lowest order concept and builds up to the highest order concept of chemical compounds through mixture, physical state, chemical change, physical change and elements. The authors also provide a separate hierarchy for theoretically related concepts. However, whatever edifice is constructed using these sorts of aids, the idea of chemical change remains somewhere near a fundamental concept. Thus, failure in understanding the basic concept of chemical change will lead to problems with higher order concepts such as ‘bonding’. Shayer using a Piagetian perspective studied the pupils' understanding of scientific concepts in the Nuffield Combined Science scheme (UK) which was designed for lower ability pupils in the 13 - 15 age range. In the section of the article on chemistry several topics related to burning, which is inclusive of the concept of chemical change, were researched (Shayer, 1978, p. 220). Shayer found that lower ability pupils have considerable difficulty with this area (c.f. the research by Donnelly and Welford (1988) quoted earlier). For example with concepts relating to the interpretation of experiments on burning hydrogen to form water, facility levels on two questions were 11% and 17% respectively. Shayer considers that the pupils' poor understanding of this area is caused by them not having reached the appropriate Piagetian level.

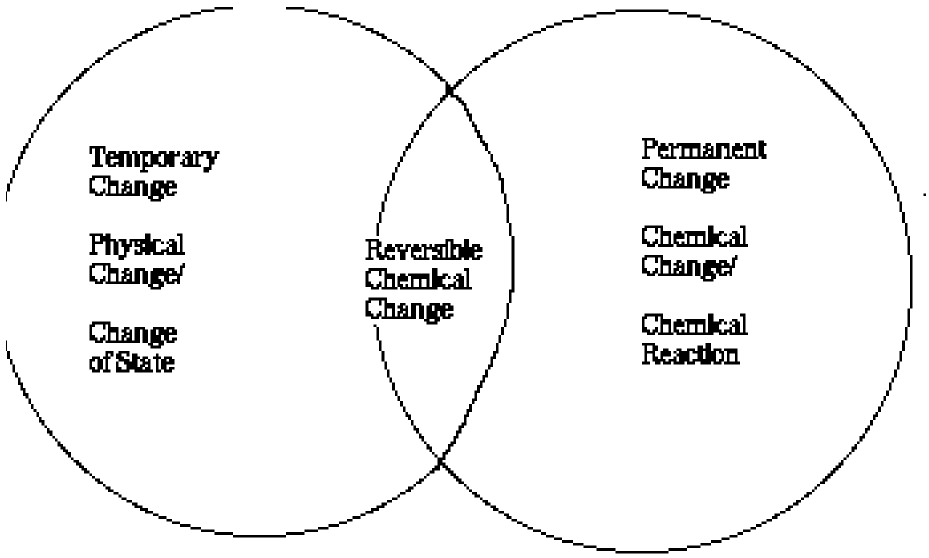
More generally Johnstone (1982) has looked at the difficulty that pupils face early in their study of chemistry. He concludes that their difficulties arise because pupils are asked at too early an age to move from the large scale descriptive and fundamental chemistry, through the representational stage of formulae and equations to the micro scale chemical approach when atoms and molecules are considered.

Figure 2.

PHYSICAL CHANGE	CHEMICAL CHANGE

Alternatively the, Venn diagram below, may expand on the simple model and add clarity.

Figure3



A Venn diagram of physical and chemical change (Viz. Atherton and Lawrence. 1978).

Recent research by Stavridou et al (1989) has shown that the reversibility of a reaction is the most important single concept used by students to distinguish between physical and chemical change successfully. Also a recent neat definition by Suslick (1989) stated that 'chemistry, after all, is the interaction of energy and matter'. I have used these and other sources to suggest an improved teaching model to explain types of change as a spectrum or continuum of change.

Difficulties are compounded because experienced chemists demand great mental agility of their audience as they make mental leaps between the representational, macro and micro scales. Pupils, who lack experience of these mental gymnastics, are left bewildered. Perhaps the problem lies in the loose way in which chemists use some fundamental words and this may cause the conceptual structure of students to be shaky. There is certainly adequate evidence of this.

The use of the words 'compounds' and 'molecules' are criticised by Padley (1988). Smith (1982) is critical of the use of the word 'element'. The word 'valency' should be banned (that was the view of the authors of Nuffield Chemistry), though Wilson 1987 in his survey found most teachers in UK schools still use the idea of valency. There is no word which expresses 'a molecule of sodium chloride' (the expression implies that sodium chloride is in its vapour state). Changing the definitions of words, such as the 'mole' also causes pupils unnecessary difficulty, but I think that linguistic problems such as those stated above are peripheral rather than central to pupils' difficulties with chemistry.

Research in educational psychology and linguistics may well influence the teaching of chemical change for the better, but is unlikely to be able to conclude that any particular teaching method is the final solution to the problem.

MODELS

The model used so far has been:-

Figure 4

	← Decreasing energy more easily reversible	Increasing energy → less easily reversible

Energy	No energy needed	little energy needed	much energy needed	huge amounts of energy involved

Change →

	No change	Physical change	Reversible chemical change	chemical change	nuclear change

Structure	Structure stays the same	Movement of molecules	Interchange of atoms	Change of subatomic particles

F1gure 4 Spectrum of change or Change Continuum.

This model may not hold up in all circumstances but it does offer a better model at this level than any we are currently using. For example water changing from liquid water to steam is always given as a prime example of physical change in junior classes. However considerable energy is needed for this change and many hydrogen -oxygen bonds involved in hydrogen bonding are broken (Asimov, 1983) so considering these criteria, it could be argued that boiling water should be classified as a reversible chemical change. The model above can represent this change by placing the boiling 6f water between physical and chemical change. The model thus accommodates changing knowledge as the student progresses, without having to 'unlearn' wrong information which was a fault of the simpler classification systems. The model will also accommodate the concepts of nuclear fission and fusion.

PRACTICAL SOLUTIONS

One current view of chemical education is that by looking at a variety of good practical applications of chemistry, provided that these sustain the interest of children, an understanding of basic principles can be engendered. This is possible and a number of courses such as the Salter’s course of the University of York, (Lazonby and Nicholson, 1988) or Chemcon (A.C.S, 1988) now exist. These applications-driven courses may lead most children to better theoretical understanding than they at present obtain from theory-driven course, but the long term effect of such courses for all children still has to be evaluated.

The following practical suggestions, not all of them new, may go some way towards effective, consistent long-term teaching of the idea of chemical change:

1. Ideas of change should be initiated in the primary schools.

Ideas for interesting and imaginative investigations at this stage are needed. One such suggestion (Symington, 1988) involves cooking, so that changes can be seen and indeed tasted; this sort of investigation should lay the right attitudinal foundations for science in secondary schools. The Elementary Science Study booklet (E.S.S, 1971) on Mystery Powders and more recent suggestions by Kotar (1989) are also useful scientific work with commonly available chemicals that can be carried out in primary schools.

2. Children's understanding of change of state seems to be unclear, so a wide variety of experiments involving, condensation, evaporation, solidification, melting and sublimation should be introduced in a straightforward manner at the primary and lower secondary level. As far as possible children should observe what happens and also express what they see in their own words. Variety could be increased by doing experiments such as boiling water in a paper cup (Liem 1981, p177).

3. A wide variety of experiments where there is clearly a chemical change should be used. When using the Bunsen burner for some other purpose the chemical changes occurring should be pointed out, but again the children should be given an opportunity to verbalise for themselves what is happening.

4. Burning is an example of chemical change which is common and frequently misunderstood. Kerr (1987) also gives examples of ways to clarify pupils' understanding of burning. Figure 5 represents experiments which emphasise change of state and also burning which is a chemical change.

Figure 5

PHYSICAL CHANGE	CHEMICAL CHANGE
(a) Melting candle wax	Burning a candle
(b) Melting solid sulphur	Burning sulphur (with care)
(c) Fermentation of sugar (chemical change) followed by distillation	Burning the alcohol formed
(d) Collecting gas from a cigarette lighter by displacement of water. (Palmer, 1986)	Burning the gas collected
(e) Remove the head from a match and grind to a fine powder. Notice the change in colour.	Use matches as rockets (Liem, 1981,p. 295)
(f) The lighter fuel cannon (Liem, 1981, p 150) Prior to lighting the lighter fuel has changed to a gas.	After lighting, a chemical change has taken place.
(g) The angry bucket (Liem 1981, p 140) Prior to lighting the powder is mixed with air.	The explosion is certainly a chemical change.

5. When looking at films of industrial processes teachers can prepare a worksheet for students to fill in during or after the film, with some questions enquiring about physical or chemical changes which they have observed taking place in the film.

6. When students are good at considering changes which can be easily placed in the change continuum they are then given changes which are more difficult to place, e.g.: The following are some examples of this:-

(a) Heating ammonium chloride (Reversible chemical change)

(b) Heating sand (no change)

(c) Heating zinc sulphate which is yellow when hot and white when cold (reversible chemical change?)

(d) Dissolving sugar in water which is a (Chittleborough, (1974) physical change

(e) Dissolving sodium hydroxide in water which is an example of a chemical change (Chittleborough, 1974).

(f) Comparing Plaster of Paris before adding water and after it has set.

7. One of the possible problems identified for students understanding chemical change was a lack of clarity of associated concepts. Perhaps ensuring the availability of good books some to clarify these ideas for teachers and some available in the classroom would be a major help.

For example Snape, (1989) to promote student familiarity with the elements, Atkins (1987) as a teacher's and student's resource to show a variety of different molecules and Selinger (1986) for a teacher's reference for the chemical .composition of commonly available market products. Also to give teachers a good idea of existing and colourful chemical reactions, r would recommend Gipps and Friedman (Undated), Iddon (1985) and Shakhashiri (Volumes 1, 2 or 3)

8. When topics like environmental issues are dealt with we should explain the chemical reactions taking place. For example in explaining the ozone problem, articles like that in Helix (1989) are helpful to student and teacher alike.

9. In all future cases of change teachers should state "en passant" what sort of change occurred. They should emphasise the reactants and products of any reaction. They should also try to prove occasionally what product or products were formed.

The above suggestions if carried out would clarify through sound pedagogy the concept of a continuum of change.

CONCLUSION

This paper itself follows the main lines of research which can be followed in seeking answers to questions.

The following steps were taken:

(a) Seeing what discourse between professional educators and professional chemists can offer.

(b) Seeking results in research on children's science.

(c) Seeking research findings from major international surveys.

(d) Seeking research results in continuing national surveys.

(e) Finding out what solutions educational psychology can offer

(f) Attempting to make a model to represent the areas of greatest conceptual difficulty.

(g) Strengthening the findings above by using sound pedagogic principles.

The above are the stages by which an answer may be sought; the conclusion is that if the teacher considers a particular concept to be of fundamental importance, sufficient time has to be allowed for the topic to let most children gain a sound grasp of the topic. A variety of methods tried over a lengthy period of time will probably be required to build a sound conceptual structure.

If whilst at school people obtained a clearer picture of what is meant by chemical change, then perhaps when they were adult they would make sounder decisions about those great environmental and health issues of our age in which chemical change plays a part.

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