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ABSTRACT

More than five hundred chemistry/science text books from a variety of countries and written at all levels of education have been looked at to see how they dealt with the topic of physical and chemical change. Textbooks have continued to cover this chemical topic for over one hundred years. What evidence do school textbooks contain about the purposes and methods of teaching this topic? Is its coverage in textbooks increasing or decreasing? Does its coverage vary by country, by level or by degree of integration of the sciences? When was physical and chemical change first taught and is it still appropriate to teach this topic? These and other related questions will be considered in the paper.

PHYSICAL AND CHEMICAL CHANGE AS VIEWED THROUGH SCHOOL TEXTBOOKS: AN INITIAL VIEW.

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More than five hundred chemistry/science text books from a variety of countries and written at all levels of education have been looked at to see how they dealt with the topic of physical and chemical change. Textbooks have continued to cover this chemical topic for over one hundred years. What evidence do school textbooks contain about the purposes and methods of teaching this topic? Is its coverage in textbooks increasing or decreasing? Does its coverage vary by country, by level or by degree of integration of the sciences? When was physical and chemical change first taught and is it still appropriate to teach this topic? These and other related questions will be considered in the paper.

INTRODUCTION

Initially I became interested in this topic, because I believed it was an area that my students did not understand properly. I decided that as one strategy for investigating this area further, I would see what could be gleaned from school textbooks. Although I hope that my thesis will answer the questions in the abstract, this paper will answer only some of them as research in this project is ongoing.

Previous observation of school science texts showed that some texts mention physical change and chemical change together, using them as a means of classification of all types of change, whereas other books treat them separately or mention them in different parts of the book under a bewildering variety of names. It is not possible to have a science/chemistry textbook that avoids all mention (overt or covert) of physical and chemical change. For example, the word 'physical change' may not be mentioned, but if the ideas of grinding, mixing, evaporating are present, then physical change is implied. If, for example, the text names a chemical compound, includes an equation, describes a substance decomposing on heating, or gives a theoretical explanation of chemical bonding, then a chemical change is implied. This is pursuing the topic to a logical, but not a very practical conclusion. If this implied definition were accepted, then the idea of chemical and physical change is a part of all science textbooks as a matter of course. However it would not necessarily mean that the sort of change observed when grinding a solid to a powder (a physical change) was compared and contrasted (opposed) with the sort of change seen when a new substance was formed after heating a mixture of substances (chemical change). Some textbooks do oppose 'physical and chemical change' and presumably this is for a good reason. What seems probable is that 'physical and chemical change' is as much a way of teaching and classifying as it is a scientific concept. When categorising textbooks, I will thus consider those that oppose physical change and chemical change as a group as compared with those that mention physical change or chemical change separately or do not mention them overtly at all.

The fact that the topic 'physical and chemical change' had been a regular part of textbooks was obvious at an early stage of this research. Initially I estimated that 1850 could be a starting date for my study of textbooks, as I thought this would be roughly when the use of the term 'physical and chemical change' had started, but currently I have decided to search actively for older textbooks and to include them in the list, whatever their date of publication. The reason for the change of plan is that a variety of other phrases such as cohesion and affinity seem to pre-date the phrase 'physical and chemical change' and appear to have approximately the same meaning.

There may be reasons other than pedagogical ones for opposing physical and chemical change. Because I am also working in parallel on disputes about 'physical and chemical change', I am conscious that in some instances there may be non-scientific or sociological explanations for the lengthy period that 'physical and chemical change' has stayed in junior chemistry and general science text books. At an early stage I put forward four possible alternative hypotheses to explain the longevity of the concept. 'Physical and chemical change' may have remained in school science/chemistry curricula because:

(1) The concept is a remainder of an 'Aristotelian' theory of matter, kept by the natural conservatism of scientists.

(2) The opposition of 'physical and chemical change' in textbooks is a pedagogical device, so that it is easier for students to learn related concepts.

(3) The concept is often illustrated by a number of exciting and interesting experiments that appeal to those teachers who see themselves as being practically orientated.

(4) The concept is a device used by chemists to define the boundary between chemistry and physics to the advantage of chemistry, so that young people will tend to choose chemistry as a subject to study rather than physics.

THE FOUR HYPOTHESES

It is possible that more than one of these hypotheses is true or that there are additional explanations but it is hoped that the study of text books will throw some light on the truth or falsity of these hypotheses. I will give some initial explanation of each of these in turn.

Hypothesis 1 Many theories of matter have evolved over the past two and a half thousand years, so that at different periods in human history the concept of matter has been perceived very differently. Chronologies of these theories usually start with the view of Thales of Miletus, who lived in about 500 BC, that all matter was made of water (Mierzecki, 1990) and move through a bewildering variety of theories, to a comparatively modern view of matter, such as the Bohr/ Rutherford theory of about 1915 (Ihde, 1964, p.500) that tends to be the basis of the theory current in school textbooks. The current scientific view of the nature of matter has moved a long way from the Bohr/ Rutherford theory, but there is still no certainty about the absolute nature of matter (Mierzecki, 1990, p.91) and perhaps there never will be.

There is however at least one part of the Greek philosophies of the nature of matter that remains in the concept of 'physical and chemical change'. That is that Aristotle (and

Western civilisation for the next 2000 years) believed that matter was made of the 'elements' called air, fire, earth and water. These had properties related to them and the four elements and their related properties were expressed as two pairs of opposites. The words 'physical' and 'chemical' in the phrase 'physical and chemical change' are also opposites with characteristics that are opposed in a similar way to 'Aristotelian' theory.

There is another different sense in which the concept of 'physical and chemical change' has taken over pre-existing Greek ideas of atoms. In many textbooks, mainly of the 1960s vintage and later, the idea of moving atoms and molecules is an essential part of the explanation of 'physical and chemical change'. This is perhaps only a weak linkage in that the early Greek understanding of atoms is very different to current understandings.

Hypothesis 2 It is very noticeable that the words 'physical and chemical change' do not occur as a theory of matter in histories of chemistry or even in the majority of chemistry books written for scientists. The phrase 'physical and chemical change' is not usually found in research papers though there are exceptions (Dewar 1911). Otherwise the term is only found in school textbooks and sometimes in books for adults considering the nature of matter in historical or general terms. The term is absent from most dictionaries of science. That is that the phrase seems to be more or less completely limited to those who are chemical novices.

It is this negative evidence that makes it likely that the concept of 'physical and chemical change' is a pedagogical device for teaching in schools rather than an essential idea developed from a logical structure of chemistry. Indeed, although the concept of 'physical and chemical change' (or some phrase with a similar meaning) has been in textbooks for over 200 years, there have always been some books that avoid the opposition of 'physical and chemical change'.

Hypothesis 3 Hypothesis is more sociological in nature and evidence regarding it tends to come from sources other than textbooks, such as anecdotal evidence and letters to journals about why 'physical and chemical change' should or should not be taught. I will not be exploring this hypothesis further in this paper.

Hypothesis 4 This hypothesis is one that people generally find strange yet it is not difficult to document from old textbooks. The definitions of 'physical and chemical change' were very much a part of defining the boundary of what ‘chemistry’ is and what 'physics' is. Two examples of this follow, but the practice was common, so many others could have been chosen.

> The study of physical changes constitutes the domain of PHYSICS and the study of chemical changes constitutes the domain of CHEMISTRY. These two kinds of change are not always easy to distinguish, and Physics and Chemistry are two closely interwoven branches of science. (Jamieson, 1917)

> Changes of this kind, in which form and properties only undergo modification, without any alteration in composition, are called PHYSICAL CHANGES, and the study of this class of phenomena comes under the domain of Physical Science..........Changes of this class, in composition as well as properties, are called CHEMICAL CHANGES and the study of the laws which govern and bring about such changes constitute the SCIENCE OF CHEMISTRY.
>
> (Lewes & Brame, 1925)

The relationships between physicists and chemists over the past 200 years have certainly been variable. If we consider Lavoisier to have started modern chemistry, then we can date chemistry as a separate science from about 1780. Up to the turn of the 20th century, we can see chemists as being very much on the defensive and they thus wished to ensure that the subject had clear boundaries. More recently the worry about whether chemistry might become absorbed into physics has evaporated and chemists are confident of being a part of a subject that is a discipline in its own right.

On the question of whether chemists have used the existence of a boundary between the subjects, to make chemistry appear more attractive than physics to students at school, which is the second part of the hypothesis, I have little direct evidence, but it is certainly true that physics books do not usually mention 'physical and chemical change'. In fact, I have only found one physics book that mentions physical and chemical change (Dull, Clark Metcalfe & Williams, 1960), but there may well be others. I take the fact that physics textbooks scarcely mention 'physical and chemical change' to indicate either that they do not find the concept helpful pedagogically or that they do not wish to emphasise the differences between physics and chemistry

These four hypotheses are scarcely proved or disproved at this stage, and it may well be that they are not in a format where formal proof is possible, but they will represent a continuing train of thought within the thesis.

RECORDING 'PHYSICAL AND CHEMICAL CHANGE' FROM TEXTBOOKS

This section explains very briefly how I am extracting data about 'physical and chemical change' from textbooks. I have obtained school textbooks from a variety of sources and have photocopied from each book the title pages, preface and the pages that describe physical and chemical change, if the book has such a section. I have then categorised the information from this photocopied material in a number of different ways and entered the data onto a hypercard stack. The hypercard used is reproduced below. I will not explain here what was recorded in each space or the sorts of problems of definition that arose in making the record. However the majority of the spaces were self explanatory, though because of the variety of ways in which textbooks are written, it is difficult to be consistent in assigning categories.

Figure 1 The Hypercard Proforma. (OMITTED)

I will explain the middle section of the hypercard which records how physical or chemical change is expressed, where in the book it is used, how long the explanation is, and what examples are used. The main factor here is the consideration of whether physical and chemical change are found close together and opposed in the book, so that they are compared and contrasted or whether they are some way apart, so that they are treated individually. In the latter case the card is marked by an "S" for "separate" or in the former case it is marked with a "T" for "together". This would appear to be a very easy criterion to decide, but there were cases where the decision was by no means obvious. It is this categorisation that I will use in constructing the graph of percentages of books that oppose physical and chemical change as compared with those that do not oppose physical and chemical change. In old books (generally 19th century), the words 'physical and chemical change' are not used but the words "cohesion" and "affinity" are sometimes opposed in the same way or a variety of other phrases with a similar meaning may be opposed. In categorising textbooks "S" or "T" I have counted cohesion, affinity etc in the same way as I have categorised "physical and chemical change'. Later there is considerably more discussion about what was meant by the words "cohesion" and "affinity" at different times.

When constructing the hypercard initially I had imagined that I had allowed for all possible variations: I had certainly allowed for the main ways in which textbooks characterise physical and chemical change, but there are many additional possibilities that I had not considered. For instance, I had recently found a new textbook (Peters, 1990) and an old textbook (Kane, 1840) that use the criterion of change of colour as an additional way of distinguishing physical and chemical change, but I had left no special place to record this, so this is stated in the free space on the card. Any other difficulties of a similar kind are recorded in the free space section.

There is a question of how to decide which school chemistry/science textbook at which levels to include in hypercard stack. The definition I have used is to look at books where there is a reasonable expectation that some of the books will include a section (however short) on physical and chemical change. For example I have not used any third year university books, physical chemistry books or organic chemistry books, but I have included introductory college chemistry books, books on inorganic chemistry and a few practical chemistry books. I have also included a number of physical science texts (e.g., Addicoat, 1960: Brinckerhoff, Cross, Watson & Brandwein, 1963) and exceptionally a geology text (Brandwein, Brovey, Greenstone & Yasso, 1975). Amongst the chemistry texts, I have included a number of specialist texts, for different purposes within chemistry, such as those for nurses, health professionals, agricultural students, miners and beauticians. The view I have taken overall is to include a wide variety of chemistry and science textbooks, varied by level, type and country of origin. Although this strategy may not provide any very accurate picture of how common the teaching of physical and chemical change was in schools at a particular place or time, I believe it will give a good approximate picture.

DEFINITIONS: THE NATURE OF PHYSICAL AND CHEMICAL CHANGE

The title of my thesis is *The Teaching and Learning of the Paradoxical Concept of Physical and Chemical Change*. The problem of defining physical and chemical change accurately is part of this paradox. Amongst the problems related to getting to grips with the concept of physical and chemical change are the following facts:-

(1) The concept has no single satisfactory definition;

(2) The words used for 'physical and chemical change' vary over time and at any one time a number of such words are often current;

(3) The understanding of the concept itself also varies over time and at different levels of teaching;

The first of these problems will now be considered by including a definition of the sort that is to be found in school textbooks: the definition I have used as a starting point, is taken from an old but popular Australian text book (Boden, 1961, p.7). The book lists four criteria that may be used to distinguish physical and chemical change: these criteria represent a traditional view that considers that all changes can be categorised as either physical or chemical and this view is in itself problematic.

These criteria (numbered 1 to 4 below) used to be given to students, often as one of their first lessons in chemistry. The criteria are meant to be practical ways in which a student new to chemistry can tell if a change is physical or chemical. Students might well have been asked to learn these definitions by heart. A clue that this memory work was common practice, is the suggested use of the mnemonic (MISE) (mass, irreversible, substance, energy) to help students remember the difference between physical and chemical change (Atkinson, 1974).

The following features of this definition of physical and chemical change as indicated are unsatisfactory (Note- The criterion for physical change is given first with the criterion for chemical change given after the slash):-

Criterion 1 ‘No substance formed or destroyed/ Substances changed-new substances formed.’

Comment. This criterion is unsatisfactory because the learner has to have considerable chemical experience before deciding whether or not a new substance is formed. When water changes to ice, it is difficult to know whether ice is a new substance or not. To the naive observer ice certainly looks very different to water and the observer might well be tempted to call ice a new substance. As will be seen later this particular commonly quoted example can cause considerable disagreement.

Criterion 2. No change in weight/ Change in weight

Comment. This particular criterion is of dubious value (generally it is untrue) and really only applies to the case where one or more of the products is a gas that is not included in the weighing. In all circumstances Lavoisier's Law of Conservation of Mass applies. In my view, this criterion is so limited in application that it should not be included with the other criteria. However it is part of the definition given in some textbooks.

Criterion 3. Reverse change easy/ Reverse change difficult.

Comment. Generally a helpful definition for students, but there are exceptions and it is possible to apply the criterion incorrectly. For example in the case of salt being dissolved in water to form a solution of brine, the fact that the salt can be recovered by boiling all the water off is used by some books to prove that the dissolution of salt in water is a physical change. Consideration of the problem on an atomic scale would lead to the conclusion that the dissolution of salt in water was a chemical change. There are textbooks supporting this view too.

> The tearing of paper, melting of ice, or dissolving of salt and sugar in water are all examples of physical changes. ..... (Baker & Allen, 1965)

> A chemical change involves electron cloud interactions between the atoms of the matter involved. (Baker & Allen, 1965)

The two quotations above are on the same page of the same book. They are interesting as in one it states that salt dissolving in water is considered to be a physical change and in the other quotation chemical change is defined in terms of a transfer of electrons: this would cause one to define dissolving salt in water as a chemical change. The definition as a physical change also partially contradicts the view of solution expressed earlier in the same chapter (p. 14). One could come to the conclusion that it is not only students but also authors who have difficulty in understanding the definitions of physical and chemical change. To be fair, the error of considering that the dissolution of sodium chloride in water is a physical change is a common one and it could be argued that at an introductory level it was an appropriate classification, but some element of consistency is necessary.

Criterion 4. 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.

Comment. It is not always true that all chemical reactions produce or require more heat energy than all physical changes. Although there would be many exceptions, this is generally a helpful supplementary criterion for students. In fact those so-called physical changes that require anomalously high amounts of energy may be suspected of being chemical rather than physical changes.

DATA ON PHYSICAL AND CHEMICAL CHANGE IN TEXTBOOKS

I will now present the data obtained by looking at 527 texts from a variety of countries, levels and types of book. From 1801 to the present the number of the books examined and the number of the books that show physical and chemical change in opposition (or some phrases with a similar meaning in opposition) were recorded at intervals of ten years. The data obtained is shown in Tables 1A & 1.B (NOT AVAILABLE HERE). It gives a general indication of whether some, most or all books in given ten year periods treated physical and chemical change together or not. It has to be pointed out that in the early books and in the most recent books the sample size is small, but as research continues this will improve.

Figure 2 (NOT AVAILABLE HERE) is a line graph that illustrates this data and it is quite revealing. Firstly I should explain that I am using a line graph, when it would be more appropriate to use a bar graph. Nonetheless it does illustrate the point I wish to make very dramatically.

A brief look at the graph (Figure 2) does show that for most of the time between 1830 and 1994 most science chemistry textbooks have opposed physical and chemical change (or some other words that we consider have the same meaning). Looking at the graph more carefully we can observe three other features.

a) The graph gradually slopes downwards. This may indicate a gradual change in view amongst textbook writers so that fewer were using the opposition of physical and chemical change as a teaching as time went on.

b) A dramatic fall in the graph between 1860 and 1880. This may indicate a very sudden change in view amongst textbook writers so that fewer were using the opposition of physical and chemical change (or of cohesion and affinity, which would be the more common words at that time).

c)A dramatic fall in the graph after 1990. This may indicate a very sudden change in view amongst textbook writers so that dramatically fewer writers are now using the opposition of physical and chemical change.

However one should be wary about the conclusions (b) and (c) since at this stage in the research they are based on small samples. Nonetheless I believe the data is strong enough to indicate that the 1860s and the last few years were both times when the ways in which writers explained the concept of physical and chemical change were being re-formulated. Most of the rest of this paper will consider this first period (1840-1880).in the more general context of science/chemistry textbooks prior to 1900. To analyse the early textbooks further, one needs to see how the language and the concepts implied in the language implied changes in the textbooks over the period 1800 to 1900. The opposition of physical change (called cohesion) and chemical change (called affinity) occurs in many books of this period, but a variety of other terms are used as well.

THE TEXTBOOKS

The study starts with Boerhaave (1728) firstly because it is the oldest book I have currently been able to see as an original and secondly because two other authors credit Boerhaave as being the first to recognise what we would now call physical and chemical change. Graham (1847) claims that Boerhaave was the first to use the word affinity in the sense of chemical combination. (Other writers give credit to even earlier usage). However Boerhaave is the writer of earliest student textbook, and he had a greater understanding than most chemists of his day of what chemical combination involved. Read (1947, p.145) states that Boerhaave "distinguishes between chemical union and mechanical admixture" In modern parlance, he could tell the difference between a mixture and a compound. Most textbooks treat the mixing of substances as being a physical change, so perhaps we can say that Boerhaave's book was thus the first textbook to recognise, in part, the difference between physical and chemical change.

However Lavoisier's textbook, *Elements of Chemistry* (1790) defined elements, started to standardise chemical nomenclature, buried the ‘phlogiston theory’ and put forward a more coherent concept of chemical change. Lavoisier could thus be seen as someone who clarified the concept of chemical change and brought the concept much closer to the one which we have today. It is also interesting to note that Lavoisier's first major work was *Opuscules Physiques et Chymiques* (Physical and Chemical essays), published in 1774 (McKie, 1952, p. 77). It is worthwhile noting the opposition of the words 'physical and chemical', not as part of the phrase 'physical and chemical change', which is the main focus, but simply as an early date where the opposition is used.

Between 1800 and 1850 books are generally consistent in using the phrases cohesion and chemical affinity in opposition much in the same way as physical and chemical change are now used. Between 1850 and 1878 these same words appear, but with some new words too. In particular one notes that the use of the word affinity starts to be used less frequently. There are a number of possible explanations for this, and I think that the main reason is that the period is a time of ferment in terms of theories of chemical combination. This involves a lengthy explanation, but suffice to say that ‘Theory of Types’, ‘Dualistic Theory’ and ‘Structural Theory’ (Brock, pp. 210-269), were matters of heated debate at about that time. An indication of the debate, relevant to the issue of chemical change, is that one dictionary of chemistry (Watts, 1874) criticised the *Handbook of chemistry* (Gmelin, 1848) with regard to the way it used the word ‘affinity’. Watts (1874) is concerned to ensure that definitions are correct and states:-

> The terms affinity and chemical combination are not used by all writers in exactly the same sense. (Watts, 1874)

Watts' criticism is that Gmelin (1848) uses the idea of uniformity to the senses after combination as the test of affinity and thus includes solutions as being chemical compounds. Thus, as late as 1874 there is not unanimity on the meaning of chemical affinity. The problem is that the word ‘affinity’ was insufficiently precise, so this is likely to have been an additional reason for seeking a change. A number of new words came into being, such as the word ‘chemism’ used by the American Chemist Ira Remsen. He used the new word in the earliest of his books (Remsen, 1877), but it is not used in his later textbooks, where he uses the then typical opposition of physical and chemical change (Remsen, 1886, 1908, 1917).

In the English-speaking world, Roscoe & Schorlemmer seem to be the earliest authors to oppose the words 'physical and chemical' that I have found so far. In their large classic text (Roscoe and Schorlemmer, 1877) they use the phrase ‘physical phenomena and chemical phenomena’.

The first textbook I have found to oppose physical and chemical change (using those actual words) is a book by Valentin (Principal Assistant at the Royal College of Chemistry, Science Schools, South Kensington) in 1879. In the preface, Valentin (1879) refers to obtaining the experiments for his textbook from Dr Frankland. Argles (1964) in a brief description of the Royal College of Chemistry connects Frankland and Roscoe as being a part of Hoffman's research school at the College. It is not unlikely therefore that Roscoe would have influenced Valentin's ideas. Valentin (1879) also mentions in his introduction that he had based his theoretical explanations on Von Richter's *Introduction to Inorganic Chemistry* (a German work). In a later edition of an American translation of Von Richter's *A Textbook of Inorganic Chemistry*, Von Richter opposed ‘physical phenomena and chemical phenomena’, so a German / continental origin of the idea is possible.

There is also evidence that the cementing of the phrase 'physical and chemical change' into a part of the majority of textbooks over a long period of time relates to the coincidence of Valentin being in a senior teaching role within a government department that also set the examinations. Turner (1927, p.115) states that an examination system was promoted by the Science and Art Department in science subjects at about this time (1872). It may well have played a considerable part in cementing the concept of physical and chemical change into science curricula. For example Turner, (1927, p.116) goes on to state that:

> The boys were familiar with much of the ground by such a large text book as Roscoe & Schorlemmer's Treatise on Chemistry. But the whole trend of teaching was towards the acquisition of knowledge which could be readily reproduced in examination papers. (Turner, 1927, p. 116)

This is my current theory, though I would hope to substantiate it better in my thesis and that further study will enable me link examination syllabi of this period more closely with the treatment of physical and chemical change by textbooks.

I have also found in the last few weeks an early Canadian school textbook (Meilleur, 1832, pp. 15-19) written in French, that certainly opposes physical and chemical properties, discusses chemical change, and defines cohesive attraction (cohesion, attraction of aggregation) and chemical attraction or affinity. However although the basis is there the simple opposition of physical and chemical change is not there and the 'Lavoisierian' confusion about heat, light and electricity being 'imponderable' elements still remains.

CONCLUSION

Although the ideas regarding physical and chemical change that can be obtained from the evidence of teaching and learning as provided by textbooks are far from final, it is evident that information can be collected and ordered in a coherent way, so that studying textbooks of the past may provide clues as to the best ways of teaching physical and chemical change in the future.

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