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WHAT THE WORLD CHEMICAL COMMUNITY THINKS ABOUT THE CONCEPT OF PHYSICAL AND CHEMICAL CHANGE?

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ABSTRACT

The concept of physical and chemical change is far from being the clearest and most self-explanatory concept in the world. If a number of chemists are asked to define physical and chemical change, there may well appear to be a fair degree of uniformity in their answers, until a few examples are suggested. When chemists are asked to place a variety of changes into the category of physical or chemical change, then differences inevitably arise. It is not difficult to demonstrate this by viewing school textbooks and articles about the topic. In spite of this, physical and chemical change is still taught in most in most secondary school courses.

The problem arises from the definition and the historical layers of meaning that have grown around the concept, almost by accretion, without teachers being aware of their significance. The purpose of this paper is to describe the answers given by experienced educators to a questionnaire, which attempted to find out what the views of science educators/ chemists worldwide about physical and chemical change now are.

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INTRODUCTION

I have been involved in research on a number of aspects of physical and chemical change for the last five years. I have looked a number of aspects of physical and chemical change through the available literature and have written a number of papers on this concept, the most recent being Palmer & Treagust (1996). The search so far has been largely historical and I have been interested in several scientists including Lavoisier (Palmer, 1995a). However interesting these forays into the past may be, there comes a time for studying the present and perhaps even daring to predict the future. I therefore decided to construct a questionnaire to find out what various groups concerned with chemical education might think of the teaching and learning of physical and chemical change .

Three years ago, when on Professional Development Leave at SMEC (Curtin University), I started to develop a questionnaire. In this development there were a number of problems.

i. I knew that amongst experienced teachers the topic of physical and chemical change was controversial.

ii I wanted a lot of information from the questionnaire and was sure that I wished to avoid both the simple yes/no replies questions and three or five point Likhart-style answers to questions.

iii The study of textbooks includes USA, Australia, and UK and books from other countries, where possible. Similarly I wanted to make the survey as international as possible.

iv I was aware at the start of the possibility of using the internet, but I was not aware of how powerful a tool, it might be.

v I knew I wanted to ask questions to different groups of people, who would have different areas of expertise. I wanted to count as equally valuable the craft-knowledge of teachers, the educational knowledge of teacher educators, the content knowledge of university lecturers, and the perspectives of historians of science. I also wanted the perspectives of specialists of other sciences and of scientists outside the educational world.

QUESTIONNAIRE CONSTRUCTION

With these thoughts in mind I constructed the questionnaire containing 58 questions and an introduction including definitions and some references quotations and earlier research findings: I trialed this on about ten colleagues on the course with me. In the end I only got a couple of responses.

I read round the subject, including (Educational Computing Services, 1990) but the advice I got did not seem to give my respondents the freedom to answer the questions that I felt they would need. I produced coded questionnaires, shorter questionnaires, and different questionnaires for different respondents, but was not satisfied with any of the products.

There was worse to come. I re-jigged the questionnaire with boxes to define the spaces for answers and took some copies with me when I gave a lunch-time talk at King's College, London (i.e. "The paradox of physical and chemical change: an initial view", a seminar with postgraduate students and staff at the Faculty of Education, King's College, London, on 8 December, 1992, 12.30 to 1.30pm). The talk appeared to be reasonably successful, but the questionnaires were criticised as being too long and too enclosed.

I left the issue for about a year. I then found a London University Master's thesis (Dunlop, 1991). Dunlop was also looking at a complex chemical topic in which he was searching for unifying themes in chemistry. The ideas were abstract and he used the device of seeking expert advice. He contacted a number of noted chemistry educators by phone, and asked if he could interview them. He then gave his interviews asking standard questions or if an interview was not practicable, he wrote a standard letter. The actual numbers are not stated, but the author states that:

> "Some of the written replies that I received from chemical educators are included in Appendix B. I decided the personal approach was preferable to other, less personal approaches, like sending out hundreds of questionnaires to people I would have no other contact with."
>
> (Dunlop, 1991, p.52)

As I looked at the letters/ interviews and was aware of the experience and authority that their views represented as I knew about half the respondents personally or by reputation. Dunlop's thesis gave me an idea that I thought that I could develop.

I changed the questionnaire in the following ways.

- I rewrote the introduction dividing into sections so that it would contain the research references and definitions, with the idea that all respondents would be replying with a set of common understandings as a starting point. I also felt that the background information might be genuinely interesting to respondents.

- I cut down the number of questions and reformatted so that there was no space to answer questions. Respondents could answer on a separate sheet. There were then five pages of information and five pages of questions.

- The questions were in sections. These were-
  General information about respondents (6)
  A history section (4)
  A personal section (4)
  Definition of physical and chemical change (5)
  The teaching of physical and chemical change in schools (13)
  More pedagogy and the boundary between physics and chemistry (6)
  A section for book authors only (4)

- One feature I decided upon was that either I would interview the respondent, or give them the questionnaire personally and explain how to use it at a conference or some such meeting.

I started with the new questionnaire in January 1995 and after extensive travels in UK and USA, I had only given out three questionnaires of which only one was returned until recently. I was somewhat discouraged and wondered if I could get the project off started satisfactorily.

In November 1995 I was present at two history of science conferences in Minnesota and in January 1996 attended the annual ASE meeting and associated meetings. I also conducted an interview with Dr Alex Johnstone and had discussed the topic with Dr David Knight at Durham. Dr Knight preferred the written questionnaire to a tape recorded interview. At this stage I had given out personally about 30 questionnaires and replies started coming in quite well.

As I was on professional development leave again in the first semester of 1996, I decided to extend the project, so that respondents came from suitably diverse backgrounds. I had been a member of the Chemed-L listserver group for some years. I was familiar with the names of those who responded fairly frequently, and through their replies was fairly sure which members of the group had a wide experience and knowledge of chemistry. For a few weeks I wrote a standard e-mail letter (Appendix 3) to picked individuals from the Chemed-L. The letter does point out that the questionnaire is lengthy and I found about half those I wrote to said that they would reply. More than half of those who said that they would reply actually responded. In general I was very pleased with these responses, pleasantly surprised that so many people gave so much time to this questionnaire.

I further extended the list of possibles to some HPSST listserver members, some Chemconf listserver members. I also wrote or e-mailed some British Society for the History of Science (BSHS) members (very unsuccessful), some ASERA members, some local NT science teachers, and some colleagues from SMEC, some friends overseas. Generally I discovered the truth of the law of diminishing returns. I had wanted to make the survey truly worldwide and the last attempts tended to be people outside UK, USA and Australia. Language difficulties, technically unreliable systems and various other factors have tended to reduce overseas responses. In the end I received 80 returns, more than half of those who promised a response, but probably below one third of those who had invitations sent.

Throughout the process of making invitations, I encouraged responses by taking a liberal stance allowing as much freedom as possible to respondents. I pointed out that not all questions need be answered (I eventually accepted about four short written responses that did not answer the questionnaire specifically, but which explained a viewpoint). I also accepted the response by whatever means it was dispatched (e-mail, e-mail attachment, disc, taped interview or a tape sent by the respondent, typed, or handwritten): I also sent up to three reminders.

I interviewed on tape and had transcribed interviews with Dr Alex Johnstone (as stated), Dr Robert Bucat (University of West Australia), Mr Glen Chittleborough (University of South Australia) and Mr Tom Kenney (USA), who preferred to tape his response. These are the longest responses running to 20 pages or more. Other responses are generally about 3-4 pages long. The total quantity of material is about 350 pages. In this paper analysis of the results will be to look at the various sections and describe the range of views. I should say here that the wealth of experience of the respondents, their qualifications, and their interest is the guarantee of the reliability of the conclusions, though this is dependent on my interpreting this data correctly. I do not feel that any conclusion can have statistical validity: eighty respondents drawn from the world's science education community at all levels is hardly likely to achieve this. However the sample is largely drawn from those who communicate their opinions to others to others, whether by the internet or at conferences and are therefore likely to be influential. I will give a brief overview of the various sections of the paper.

THE RESPONDENTS: PERSONAL

Appendix I lists the names of those kind enough to take part in this survey in alphabetical order. Appendix II lists the respondents in terms of how they responded to the questionnaire ,their country, the sector/level in which they work, and their subjects. Appendices III, IV and V provide information relating to the questionnaire.

Australia (29%), USA (25%) and UK (16%) were the countries most strongly represented. The remaining 30% of replies were spread around 19 other countries. The male female ratio in the survey was 82.5% to 17.5 %. This is unbalanced, but it is at least partially attributable to the reality of the gender balance in tertiary chemical education. Part of the survey also required access to and use of listserver groups. Because of movement between sectors these figures would only be approximate: about 28 % of the sample was involved in teaching (primary and secondary): 26% were involved in teacher education: 41% lectured at a tertiary level and less than 5% worked in industry or research. The great majority of the respondents (90%) were at least partly involved with chemistry as a subject. There were about 5% of respondents for whom physics was a main subject and also about 5% of history of science respondents.

Overall the academic level of respondents was very high with 58% of respondents having a doctoral degree. Most of the remainder had master's degrees and several were currently pursuing doctoral studies. Eight professors/ associate professors took part in the survey. All participants had a first degree. I did not ask directly about experience, but there were several who confessed to more than thirty years experience: I would estimate that overall the group would average 15- 20 years experience per person. The question is what does this well-qualified and highly educationally experienced group think about whether physical and chemical change should be taught in schools or not. However the first section starts with history of science.

HISTORY SECTION

In this as in other sections, there are few generally held views and even in the case where some propositions are overwhelmingly supported, I feel that we are unable to say that the minority are wrong. I will examine the section looking at each question in turn.

In Question 7, participants are asked to associate the name of a scientist with physical and chemical change. Generally the reply was negative (only 21 answers with names). I will put a list of scores down as an obvious illustration that this is not the way to decide this point.

Lavoisier	8 mentions
Dalton	7 mentions
Boyle	3 mentions
Boerhaave	1 mention
Venel	1 mention
Vernon Harcourt	1 mention
Einstein	1 mention

My view was that one of the earliest scientists to grasp some portion of the concept of physical and chemical change was Boerhaave. In this question one historian of science mentioned Boerhaave, one mentioned Venel, and one mentioned Vernon Harcourt. The majority mentioned Lavoisier and Dalton. However the majority are not incorrect. Lavoisier and Dalton certainly helped to put together major parts of the jigsaw. However the advice will enable me to check the available literature to see what role, if any, Venel and later Vernon Harcourt played. One can conclude that those without a specialist knowledge, but with a good general knowledge of chemistry give Lavoisier and /or Dalton almost all the credit for the understanding of physical and chemical change. The majority view is not necessarily correct.

Question 8 is more broadly based asking whether teachers were broadly sympathetic to the use of historical material in teaching school chemistry. This must be a "motherhood" view nowadays. There was only one partially opposing view:

#39 (i) Some historical context is useful, but should be minimal
(ii) Students need to spend time on basic principles and how to apply them.

The opposite view was put strongly:

#77 I am very much for the idea of using the development and establishment of ideas in a historical context. I often assign questions and areas of private study on the basis of "how do we know?".

Surprisingly the historians with the support of some others added 'caveats' that the history should be soundly taught. However in the questionnaire as a whole this was the question answered with the greatest degree of unanimity.

Question 9 was a question for the specialist historian and most respondents ignored it. The few replies I received should prove useful.

Question 10 asked why the concept of had lasted so long. Four possible answers , though respondents were free to offer their own explanations. The explanations were as follows.

(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.

Most respondents answered this question. A very few respondents put alternative hypotheses: these tended to relate to teachers avoiding change as they were traditional. Respondent #65 explains it this way.

> Not really, I feel that it has stayed persistent because no one really writes a new textbook. They just start with what they had as an undergraduate or what they teach in today and try to "tweak" it a little. In the USA, I think part of the blame is a course that we teach in virtually every state at some grade level(s), Physical Science. This course is normally composed as 1/2 a year of chemistry and 1/2 a year of physics. It is often taught twice once in the early junior high years, grade 5-7, and a second time early in the high school years, grade 9 or 10. This course is usually presented as a non mathematical or non rigorous presentation of the "essential" parts of chemistry and physics. It obviously cannot reach the depth of understanding to teach "all" of the important concepts in chemistry and physics and is therefore a survey type course. Chemical change and physical change fit in very nicely as a definitional type of introduction to the differences between physical change and chemical change.

Respondent #77 sees it this way;

> I tend to agree with the proposition in Section C(4). The phrase is meaningless in the light of current knowledge. It should be ignored, hoping that those who believe in it, or worse, trying to propagate it, soon die out.

The actual figures for this are as follows :
Those choosing just one hypothesis.

Only hypothesis 1	3 mentions.
Only hypothesis 2	24 mentions.
Only hypothesis 3	3 mentions.
Only hypothesis 4	0 mentions.

Some chose several different hypotheses together or even all four at a time.

Hypothesis 1 with others	4 mentions.
Hypothesis 2 with others	12 mentions.
Hypothesis 3 with others	13 mentions.
Hypothesis 4 with others	11 mentions.
Altogether hypothesis 1 total	7 mentions.
Altogether hypothesis 2 total	36 mentions.
Altogether hypothesis 3 total	16 mentions.
Altogether hypothesis 1 total	11 mentions.

It may perhaps be concluded that the use of the phrase 'physical and chemical change' in textbooks is a pedagogical device to enable students to understand chemical change better.

PERSONAL HISTORY

The purpose of this section is to provide some experiences from respondents to see how well they remember physical and chemical change from their schooldays, which leaves question 12 as the central question in this section.

Question 14 links with question 30 on issues, but adds the personal dimension where the respondent states how physical and chemical change has influenced them. It tends to be the place where those who agree with the teaching physical and chemical change start to diverge from those who disagree with the teaching physical and chemical change.

Question 12 asks about what respondents remember from being taught about being taught physical and chemical change from their own school days. About 25 out of 80 respondents had some specific recollection of being taught physical and chemical change, but most respondents recollect little. I have recorded what each respondent wrote under a number of different categories. Some responses appeared to be bound up with some feeling (emotion) such as enjoyment, excitement or boredom. From others there is a straight description of what they remember: some of these descriptions were of the iron filings /sulphur experiment or copper turnings/sulphur experiment about which I have written previously (Palmer, 1995b). It is interesting to note that here, where in theory, there is a single experiment that respondents remember, their memories of it are very different. Others remember how they learned the topic or how they acquired a pre-knowledge of the topic or the problems they had with the definition of physical and chemical change.

<u>Emotion: enjoyment</u>

#3 The topic was exactly "physical and chemical change". We were given several substances to observe their change after heating in the flame. The entire process was enjoyable because the colour and appearance associated with each change was attractive.

#40 I enjoyed chemistry, And I enjoyed doing experiments which had spectacular results! I never made bombs or rockets - a friend of the family had lost a hand and an eye while making explosives at school, and he was an object lesson. My chief interest was in the growing of crystals. Later on, I enjoyed visiting chemical plants such as BHP, CSIRO and the .Sulphide Corporation with my father, who was a supplier of scientific instruments. I do not remember any disasters, and some of my experiments at home resulted in satisfying outcomes. I was fortunate in having thorough teachers in my early years of high school: I read a great deal (Sherwood Taylor was a great source of enjoyment to me) and I went ahead of the class in this. Priestley, Lavoisier and Joseph Black were real people to me.

#71 Physical change: The realisation that water can change from solid - liquid and gas. three states of water (solid, liquid and gas), the burning of sulfur, rusting of "bush-knife" chemical reactions such as precipitation. I found chemical reactions which produce precipitates very fascinating indeed. Observing what happens when two chemicals are mixed or reacted together .e.g. silver nitrate + ammonium chloride.

#78 Burning of magnesium. Interesting

<u>Emotion: excitement</u>

#15 The only chemical change experiment that I remember was with this same Mr. Jenkins. He mixed a barrel of aluminium scraps with something else and created a simulated volcano with some kind of detonation device. The whole school was out to watch, but we were so far away (for safety) that we couldn't really see anything.

#41 Physical/chemical change was taught in Chemistry every year. The only exciting event occurred when a 'recalcitrant' student threw a lump of sodium into a sink full of water. The physical and chemical changes paled into insignificance when compared to the emotional changes occurring in the teacher.

<u>Emotion: boredom</u>

#18 Taught in the first or second year at a Grammar School in the early 1950s i.e. to 11 or 12 year olds. It was a dry-as-dust blackboard exposition by the chemistry teacher.

#21 No recollection of first time. But what is remembered about these is boredom. Who cares? is the question that comes to mind. Not that these are not important, but I do not believe that they can be taught without an understanding of bonding, both inter and intra molecular.

<u>Plain Description</u>

#1 Physical change: change of state.
Physical and Chemical change: Iron filings & sulphur.
Physical: Mixing Fe & S Chemical: Heating the mixture.
The properties of the mixture and compound were compared.

#22 Physical and chemical change was introduced to me in a science lesson in year 8 about half way through the year. We were using a practical text book called "Discovery in Science, Practical Book 1" Baldock, R.N., Chittleborough, G., Eberhard, S.T. et al (1967). I still have a copy of Book 2 if you require a fuller reference. The lessons were pretty straight forward, clinical where examples as you described, were used e.g. boiling water, burning a match or paper.

#29 Yes, Mrs. Mason, our science teacher did talk about solids, liquids and gases (ice, water and steam) demonstrated variation in space occupied and explained it on blackboard using particle theory (Year 8?)

#34 I had my first lesson on physical and chemical change when I was 14.

#56 I can't remember being taught it for the first time, except that I know it must have been in Year 8. It is difficult to remember whether what I think was connected with physical and chemical changes really was. I remember heating things and dissolving things as generally involving physical changes because you could go back to the original appearance, etc.

<u>iron filings /sulphur experiment</u>

#1 Mentioned above

#38 I remember my first lesson in junior chemistry (1959). It was on mixtures and compounds, and that was where the emphasis was, although the concepts of physical and chemical change were embedded within it, as one example was on iron filings and sulfur - before reaction being separated with the use of a magnet. During the lesson the teacher burned a piece of magnesium. I think it was probably then that I decided that chemistry was the most fascinating subject of all. I think that there are far fewer problems with the 'mixtures and compounds' concepts than with 'physical and chemical change', though there are still fuzzy areas.

#43 Yes, I perfectly remember the experiment with sulphur and iron (eighth grade at the school).

#53 NO, not specifically the first time. I can recall the teacher demonstrating the properties of iron and sulphur, then mixing them and demonstrating the properties of the mixture and ultimately separating them (magnetically, as I recall). He then combined them by heating and demonstrated the properties of the resulting compound This could well have been the first time that I was exposed to the topic.

#57 Yes. It was exciting; the burning of magnesium in air to form white, MgO or the burning of Cu and S to form CuS.

#79 I remember iron sulfur mixture (magnets, trained ants etc), and the smell of H_2S!

<u>Rote learning</u>

#73 Usual stuff of learning definitions, which I now reject. I do not remember much of specific lessons, only that I could parrot off the answers.

#75 ...Teachers who depend on chalk and blackboard can teach this topic very effectively. I still remember learning the physical change and chemical change in school and how I tried to learn some of those comparisons by heart....

<u>Pre knowledge</u>

#37 I don't recall the concept of physical and chemical change being taught for the first time. I was well aware of the distinction from experiments I had done with my chemistry set.

Problems with the definition

#9 I can remember being taught physical and chemical change being taught at school. The thing that used to bug me about the physical and chemical change taught to me as a kid at school, they always used to make a great play about the reversibility of the physical change. I remember saying to the teacher well what about tearing up paper or breaking a glass. Where is the reversibility in that? There used to be some sort of stutterings and mutterings and being told to shut up and be quiet.

#14 SAD. It did not make sense and I found many examples that did not fit the tidy little definition. This made the teacher very angry at and with me. I also enjoyed this game as well.

#30 No, I don't remember when I learned it. I do remember discussing it with my father for quite some time afterwards, however. He is also a chemist. I remember trying to come up with examples of changes that could not be easily categorised.

In Question 14 respondents come to reflect on how the experiences they have described when learning about physical and chemical changes may have influenced their thinking about the 'big issues ' in science. At this point in the questionnaire we see the divide opening between those who favour teaching physical and chemical change and those who do not. Respondents speak very strongly on either side of this debate. A this point I will introduce a story from one of the respondents (Professor Carl Snyder), that illustrates very vividly the nature of the debate. The story is said to be true, but whether true or apocryphal, it could easily have happened.

> ...I can give you a brief statement on my views of chemical and physical change. It's best summed up in an anecdote, presumably true, I heard at the University of London.
>
> According to this story, presented as factual, a particularly capable undergraduate student approached his chemistry professor, who was among a group of departmental colleagues at the moment. The student apologised for interrupting and asked quietly if the professor would simply tell him whether the dissolution of sodium chloride in water is an example of a physical or a chemical change.

The professor answered that it is a physical change. One of his colleagues heard the brief discussion and interrupted to point out that since the breaking of ionic bonds of the crystal and the formation of new bonds of solvation spheres were occurring, the change should properly be classified as chemical. At this point still another colleague joined in with the observation that, no, dissolution of a solid in a liquid is properly classified as a physical change. Another objected that it is, indeed a chemical change. The discussion grew in the number of participants, in the depth of emotion generated, and in volume.

> Finally the embarrassed student mumbled a brief apology and left quietly.
>
> Professor Carl Snyder, 1996

I like this story for a number of reasons, largely because I want my thesis (and hence this paper) to use anecdotes where appropriate to make clear points that aid discussion. The major point of this would seem to me that in terms of science to be taught at a particular level, it is possible to hold a respectable academic opinion on either side of the divide.

The views that follow are considered views of experienced professionals. The views are categorised as those who think it is important to teach the concept of physical and chemical change those who think it is important not to teach the concept of physical and chemical change, those who wish to teach about a continuum of physical and chemical change and a query. There appears to be more of the group in favour of physical and chemical change at the moment, but not all views have been listed here.

<u>For physical and chemical change</u>

#2 Yes! I think it is as you can't understand issues to do with the permanence of atoms, hence pollutants- see the Robin Millar chapter on the Public Understanding of science in the ASE Teacher's Handbook.

#4 Environmental concerns probably involve for me a clear imagery of the persistence of certain chemical species like DDT or chlorofluorocarbons as basically not chemically changed in their transport through water or air.

#6 What an impossible Question! I guess it’s an awareness of the different scale of physical/ chemical force.

#22 ...The concept is pertinent to the big chemical picture as in most cases we are describing chemical changes and altering the balance of naturally occurring chemical cycles which involve chemical changes.

#26 The issues raised above; if I see something I try to explain it, initially, in terms of physical or chemical change (e.g. erosion, bush fire, explosions).

#37 Certainly it is potentially useful for the general public to have some understanding of chemical reactions. Ozone depletion, global warming, energy transformations, etc. all involve chemical changes. An important issue is the difficulty of chemically reversing some of the environmental damage that has already occurred.

#39 There is a tendency to look at complex problems initially in terms of whether they involve chemical reactions or not. Knowing the answer doesn't have to change how interesting the problem is, but it does help one to bring the right tools to bear in order to begin solving it. Operational science involves a systematic approach and chemical vs. physical changes are part of the traditional fabric of science.

#42 Yes I do believe that the underlying conceptual explanations related to chemical changes where there is a change of substances compared to (at least my current understanding of) physical changes where no such change occurs does assist in understanding such matters as the depletion of the ozone layer etc.

#43 I think it was a good opportunity for me to start classify the phenomena surrounding us. I think now that this was a good push to start thinking about the world.

#48 think it is important for chemists to try to have the community understand the differences, particularly when we are talking about e.g. environmental pollution and other factors that give Chemistry a bad press.

#57 Yes. The concept of physical/chemical change has implications on our current thinking of chemistry.

#59 Yes I think the concepts of physical and chemical change are of value. Especially when coupled with ideas of conservation of mass and energy, these ideas allow us to see how pollution etc. is detrimental to our surroundings.

#60 - relates physical and chemical changes to everyday happenings. Influenced by the presentation of topics and concepts.

#65 I think the molecular change = chemical change is essential to scientist solving/discussing all of your examples. Therefore, if we are going to ask students to participate as either potential scientist or even informed voters, they must be able to think about chemical changes at the molecular nature.

#71 Certainly yes. The understanding that a chemical changes involves the formation of a new product is realised by students when you start talking about the burning of plastics in oxygen - the product is hazardous. It is easier to idea about a chemical change - the evolution of a new product . In this case the evolution of a poisonous gas. You see people in the rural areas (in non- western countries do not appreciate why burning of plastic is bad because they do not know the chemistry of it, unless they understand the explanation of a chemical change and the likely products it is meaningless to continue to tell these fellows that the burning of plastic produces a hazardous gas or atmosphere ...

#72 Again, I think the concept is really about chemical reaction, and this is an essential concept of chemistry which has to be understood, either for school / laboratory reactions or for the out- of - school / environmental reactions that you mention....I think that the concept of physical and chemical change should be tailored to the context of environmental reactions in terms of additional concepts such as reaction cycles, (ir)reversibility and catalysis.

#79 Outside of chemistry, I still think in terms of reversible and irreversible change.

<u>Against physical and chemical change</u>

#9 World issues - I do not find it a useful concept at all any more. It is not a distinction I find helpful to my thinking at all.

#18 No. It seemed, at one time, to present a justification for the separation of physics and chemistry in schools and universities.

#27 It hasn't been particularly helpful to me personally.

#29 Not really. I don't think it has really influenced my thinking at all. It was just something else to think about!

#34 Now, I refuse the concepts of physical and chemical changes. There is no clear frontier between both. The modern knowledge on atomic, molecular, and solid state structure, and on the interaction between particles, has convinced me that it is impossible to assure in any case when new substances are created (Chemical change). The concept of "substance" is not well founded in Chemistry. No clear border exists between Chemistry and Physics.

#46 No, except maybe to analyse how inadequate some of the definitions are, thereby beginning a lesson on critical thinking.

#53 The concept possibly has limited value as a way of getting young students to think about change, but in view of its very serious shortcomings it is probably better not to use it. I do not believe that it has any real value in helping scientists or the general public understand major world issues. I am not aware of any influence on my thinking that I can attribute to the concept.

#56 No, I don't think it is. I think it is a misleading distinction because all changes in matter involve changes in forces between particles and their energy and to call some changes physical implies that there are no changes in forces I think my feelings have crystallised over the last ten years while teaching Senior Chemistry and I now feel the distinction should not be made at all.

#66 I can't think of any way that chemical and physical change play a particularly important role in explaining everyday chemistry. The issue I raised above just about covers it: How do you talk about the difference in what happens to water when you heat it to get a gas and what happens when you pass an electric current through it and get a gas?

#67 No. Personally I leave it out altogether. In my view it is unhelpful in general and of no particular use in dealing with any of the matters you mention in the question, nor does it give any helpful insights. It has been one of the things that has pushed me to look for better ways of teaching chemistry. I explain this more fully in a later answer.

<u>A continuum of physical and chemical change</u>

#12 They represent extremes on a continuum of understanding. As a dichotomy they are useless and probably damaging; as extremes of a range they can help beginners to think about the territory in between.

#30 I don't think I can answer this question. I don't think about the world this way. I think the value of teaching/learning about chemical and physical changes lies in seeing them as two ends of a continuum and recognising that many processes fall somewhere between the two absolutes.

#52 Actually, no. I see a continuum of interaction energies strong on one end (leading generally to chemical change) and weak on the other (leading to physical change).

A query

#33 This dual relationship of matter has caused me to wonder why so often scientific concepts occur as a Yin - Yang relationship. For example: physical/chemical; homogeneous/heterogeneous; covalent/ionic; endothermic/exothermic, cation/anion, proton/electron; etc.

DIFFICULTIES WITH DEFINITIONS

Questions 15-18 relate to the logical problems with the simple table of observations that allowed physical changes to be distinguished from chemical changes. I have to agree that the particular table chosen links an oversimplified pattern with an authoritarian philosophy. i.e. the idea that "changes are of only two types - they are either physical or chemical". Each of the definitions, whether relating to the formation of new substances, the energy evolved, the masses of the substances produced, or the reversibility of the reaction were flawed as stated and the respondents pointed out many logical shortcomings in the definitions. Such definitions were common in textbooks up to 1970s but more recently only the definition that relates to the formation of new substances, is used and the idea of physical and chemical change is given less prominence.

Question 19 however was a key question for me as it represents the point of view that whether we use them or not, we should attempt to have in place a set of logically consistent definitions. The phrase "Physical and chemical properties" is used in many contexts and the most common definition of the phrase uses an understanding of what is meant by physical and chemical change. I am unhappy if textbooks use the phrase "Physical and chemical properties", but neither define the phrase in some other way nor explain the meaning of by physical and chemical change. Unfortunately my wording and exemplars appeared to mislead respondents, so I think many respondents missed my argument.

I did receive some suggestions as to how this problem could be overcome. These were:

#19 I think we could re-define physical properties as those related to structure, where other materials are specifically excluded (melt, crack, bend, get hot, conduct ...), and chemical properties as those relating to interaction of matter (diffuse, dissolve, react) In the geographical example, physical erosion would be impact of energy, including forces from other matter that does not otherwise interfere, like a hammer impact (sand, air/wind, frost would all be physical)

#22 Physical and chemical changes are okay provided science (and other areas e.g. geography), are precise about defining physical and chemical properties upon which concepts of physical and chemical change rely.

#28 I do use the terms but without the great emphasis used in the past and I do not try to distinguish too strongly between them.

#31 . In ordinary discussion of science, I think we will likely continue to use "physical" and "chemical" loosely, and I don't see a real harm in that. I think the problem arises in school situations in which the so-called distinctions are emphasised unduly. Dissolution of a cliff of carbonate by acid rain I might consider a chemical erosion, while its destruction by wind forces I would still call a physical erosion.

#35 No, but it would be more sensible to use the phrase Scientific properties and just list the properties such as m.p., b.p. solubility, etc. This would allow for other aspects such as biological properties or changes to be accommodated.

#36 Physical and chemical - once again we talk about chemical and physical properties as well as chemical and physical changes. Again I think if we talk in terms of a spectrum might be better attuned.

#37 I suppose that interactions that fall on a continuum create problems in classification. For example, are Van der Waals forces or hydrogen bonds chemical or physical interactions? I guess I would have to say that the basis for all chemical change is physical interaction. At the atomic level, the distinction disappears. It is only useful when discussing bulk properties, just as the distinction between physical and chemical properties becomes an issue only in aggregates of atoms.

38 I think that once students have understood the basis (in terms of microscopic descriptions) of the various kinds of changes we wish to discuss, we can tell them that certain changes or properties have traditionally been regarded as physical or chemical, without trying to propose all-encompassing definitions - in the same way as the concepts of 'metal' or 'non-metal' retain their general usefulness, although it may be difficult to define these in such a way that every element fits neatly into one category or another. Stress that this is simply a matter of convenience, so that we can refer collectively to various phenomena without

having to list them separately. Quite early in their science education, students have probably encountered many other examples of arbitrary choices and human conventions, ranging from the direction defined as positive for an electric current to the numbering of the groups in the periodic table.

#42 Intuitively no because I believe I currently use such expressions automatically when discussing the types of examples to which (19) refers.

#45 Yes: physical and chemical properties. In this case, the difference depends on whether the property can be detected with the senses or not. I cannot think of a broad definition of "physical and chemical" at this moment.

#47 Properties shared by a bulk of particles (physical) and properties shared by every single particle (chemical).

#53 NO. The terms 'physical properties' and 'chemical properties' can be defined by individual specification.

#59 To define physical and chemical properties, I use an analogy of people. Physical properties are things such as hair colour, eye colour, height, etc. Chemical properties would be things such as their personality, how do they interact with other people, (and form chemicals, how do they react with other substances)

#66 Physical and chemical are used to modify change, properties, weathering, and all such, but I have never sensed a need to define the meaning in any way other than "a change in which you maintain the same basic unit of matter" vs. "a change that results in the rearrangement of atoms into different basic units."

#67 . No. However the idea of listing the properties of a substance in two groups based on whether the property depends upon other substances being present or not. e.g. Melting point can be measured independently of the presence of another substance. Solubility cannot. (I personally see this as a chemical property as explained above in (a.) of reverse change difficult.). Chemical properties include reactions with other substances. To ask the question, "Is another substance needed for the property to be determined?" allows me to pop it into the right column.

#72 . Chemical properties relate to the reaction possibilities of a substance while physical properties do not. I suppose the same applies to the changes of substances/properties in geology. I also found in older textbooks the terms *chemical* solutions e.g. salt in water or Fe in HCl versus physical solution e.g. sugar in water. And we have the chemical atom/ bond/ equilibria/ energy versus the physical atom/ bond/ equilibria/ energy. There also exist the terms chemisorption and physisorption in catalysis related to bonds differing in terms of energy. There may be others too. I suppose you could rephrase the concept of chemical and physical change in terms of reaction, energy, corpuscles and chemical bonding.

#73 Seems to me we can clearly describe change at molecular and macroscopic levels, but there may be little to be gained from classifying as physical or chemical, except in a very loose way. According to the classification almost all changes are somewhat ambiguous. Physical and chemical properties are also a bog.

#77 I rather not discuss a non-issue, such as this.

#79 I teach geology currently, and do distinguish between physical and chemical weathering. I do not treat the distinction as of importance: my approach is more that rocks may be broken down by both physical and chemical means.

THE TEACHING OF PHYSICAL AND CHEMICAL CHANGE IN SCHOOLS

Question 20 is a key question in the sense that it asks when and if physical and chemical change should be taught in schools. Whatever the result is in terms of numbers of those who favour physical and chemical change being taught traditionally and those who would like to see the concept of physical and chemical change put on the scrap heap of history, those numbers cannot have any statistical significance: they are simply the opinions of this sample of people. It is surprisingly difficult to put some replies in the category yes or no. The numbers were in fact 49, who favour physical and chemical change being taught traditionally and 20 who oppose physical and chemical change being taught traditionally. Some did not answer either Question 20 or any other question that clarified their view. Also there would be many on either side of that yes /no border who would not have a strong view for or against, whose view depended on contexts not specified in the questionnaire. The chemists really have the view that the important change for students to understand, and many are unconvinced that the opposition of physical and chemical change makes chemical change easier for students to understand.

CONCLUSION

I have to say that it seemed to me that the balance of the academic argument favoured the view that the days of teaching physical and chemical change were numbered at a secondary or tertiary level, though in terms of numbers the opposite view was more popular.

Over the next twenty years I see the concept of physical and chemical change putting on a 'new persona', for about the fourth time in its history, becoming a rough and ready concept that children learn early on without much in the way of definition that says that something 'special' has happened when one boils an egg or bakes a cake.

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Palmer, W. P. 1995b Physical and chemical change: The long history of the iron filings and sulphur experiment, *Proceedings of the Third International History, Philosophy and Science Teaching Conference,* Minneapolis, Minnesota, USA, Volume 2, October 29 - November 1 1995, pp. 939-949.

Palmer, W. P. & Treagust, D. F. 1996 Physical and Chemical Change in Textbooks: An Initial View, Research *in Science Education,* 26(1) 129-140.

APPENDIX 1
LIST OF RESPONDENTS (In alphabetical order)

Dr Trevor Appleton	Dr Alexei A.Kubasov
Dr Josefina Arce	Dr Jack Landgrebe
Mr Michael Aslin	Professor Trevor Levere
Mr Philip Bladon	Dr Edward Lindley
Dr Robert Bucat	Ms Cath Milne
Mr Ed. Byrnes	Sr Dianne Mollica
Mr Peter Calder	Dr Friedrich Naglschmidt
Dr Jim Carr	Dr Barry Noller
Professor Malcolm Carr	Norwegian PhD Student (unnamed)

Mr Dennis Chisman	Mr Mick Nott
Mr Glen Chittleborough	Dr Ernie Nunn
Dr David Clift	Professor O. A. Olubuyide
Dr John N. Cooper	Mr C. K. Or
Dr Mark Cosgrove	Ms Chris Purdie
Mr Graham Crawford	Dr Vivi Ringnes
Sr Annette Cunliffe	Mr Franco Rodie
Dr David Daniels	Dr Keith Ross
Mr Jim Ealy	Mr Gabriel F. Rshaid
Mr Peter Ellis	Dr Evgenii Rudnyi
Dr Marcia Ferraz	Professor Margaret Rutherford
Ms Hilary Fowler	Professor (Emeritus) Larry Sacks
Dr J. A. Friend	Mr David M. Schmeirer
Ms Suzanne Gardner	Dr A. Truman Schwarz
Dr Andoni Garritz	Dr Robert Siegfried
Professor John K. Gilbert	Associate Professor Keith Skamp
Dr Hal. Harris	Mr Scott Slough
Dr J. Dudley Herron	Professor Carl H. Snyder
Mr George Heys	Dr Roland Stout
Dr Martin Hollins	Dr Clive Sutton
Dr Reed Howald	Dr David Symington
Mr Warren Irwin	Dr Ternai
Ms Patricia A. Isaacs	Mr Martin Trouw
Ms Jane Johnston	Mr Berry Van Berkel
Dr Alex Johnstone	Mr Peter Varghese
Dr Jaroslav Kahovec	Mr Michael Vokins
Mr Richard Kassissieh	Dr Bruce Waldrip
Dr Tom Kenney	Dr Audrey Wilson
Dr Doris Kimbrough	Mr Gordon T. Woods
Dr Valda Kirkwood	Professor WalterYu-Jen Su
Professor David M.Knight	Mr Steve Zander

APPENDIX 2
LIST OF QUESTIONNAIRES RETURNED
(In order of being processed)

#1	Written	Male	PNG	Teacher/sec	Chem
#2	Written	Male	UK	T/Trainer	Physics
#3	By e-mail	Male	Taiwan	T/Trainer	Chem
#4	Written	Male	UK	T/Trainer	Chem
#5	Written	Male	UK	University	Hist /Chem
#6 .	Written	Male	UK/ Wales	Teacher/sec	Chem
#7	Written	Male	UK	T/Trainer	Chem
#8	Written	Male	Aust/NSW	T/Trainer	Chem
#9	Tpd intrvw	Male	UK/Scotlnd	T/Trainer	Chem
#10	By e-mail	Male	USA	University	Chem
#11	By e-mail	Male	USA	University	Chem
#12	By e-mail	Male	USA	University	Chem
#13	By e-mail	Male	USA	University	Chem
#14	By e-mail	Male	USA	Teacher/sec	Chem
#15	By e-mail	Male	USA	Teacher/sec	Chem
#16	By e-mail	Male	Canada	University	Hist chem
#17	On disc	Female	Aust/NT	Uni & primary	Science
#18	By e-mail	Male	UK	T/Trainer	Physics
#19	By e-mail	Male	UK	T/Trainer	Chem
#20	e-mail&typ	Female	USA	Teacher/prim	Bio/phys
#21	By e-mail	Male	USA	Teacher/sec	Phys/Chem
#22	On disc	Male	Aust/NT	Teacher/sec	Geol/Chem
#23	Typed	Male	UK	T/Trainer	Phys/sci ed
#24	Typed	Male	USA	University	Hist chem
#25	Written	Male	UK	Teacher/sec	Chem
#26	By e-mail	Male	NZ	University	Che/pharm
#27	By e-mail	Female	UK	Uni/prim	sci Bio
#28	Written	Male	UK	Teacher/sec	Hist/chem
#29	Written	Male	Aust/NT	Teacher/sec	Che/admin
#30	By e-mail	Female	USA	University	Chem
#31	By e-mail	Male	USA	University	Chem
#32	By e-mail	Female	Aust/QU	T/Trainer/Prim	Chem
#33	By e-mail	Male	USA	University	B-che/B-phy
#34	By e-mail	Male	Mexico	University	Phys chem
#35	Typed	Male	UK	Admin/ex teach	Chem/ISci
#36	Tape	Male	USA	Community Col	Chem
#37	Typed	Male	USA	Liberal Arts Col	Chem
#38	By e-mail	Male	Aust/QU	University	Chem
#39	By e-mail	Male	USA	University	Organ chem

#40	By fax	Male	Aust/NSW	Uni/Hist/rtd	Chem/Ind
#41	By e-mail	Male	Aust/SA	T/Trainer/Sci	Geology
#42	By e-mail	Male	Aust/NSW	T/Trainer/prim	Sci/Chem
#43	By e-mail	Male	Russia	University	Phys chem
#44	By e-mail	Male	Aust/NSW	T/Trainer/sec	Sci/Chem
#45	By e-mail	Male	Botswana	Teacher	Sci/Chem
#46	By e-mail	Male	USA	University	Gen/phys che
#47	By e-mail	Female	Norway	T.Train/sec	Chemistry
#48	Typed	Male	Aust/VIC	University	Chem
#49	By e-mail	Male	Czeck Rep	University	Resrch/che
#50	By e-mail	Male	Aust/VIC	Industry	Chem/infor
#51	By e-mail	Male	Russia	University	Resrch/che
#52	By e-mail	Male	USA	University	Gen/phy che
#53	By e-mail	Male	Aust/VIC	University	Chem
#54	By e-mail	Male	Argentina	Teacher/sec	Chem
#55	By e-mail	Female	Aust/NSW	University	Gen/Chem
#56	Typed	Female	Aust/NT	Teacher/sec	Che/Bio/Phy
#57	By e-mail	Male	Jamaica	University	Chem
#58	By e-mail	Male	Germany	Teacher/sec	Biology/Chem
#59	By e-mail	Female	Canada	University College	Gen/Chem
#60	Written	Male	Aust/WA	T/Trainer	Chemistry
#61	Tpd intrvw	Male	Aust/SA	T/Trainer	Chem
#62	Written	Female	Aust/WA	Teacher/reseach	Chem
#63	Tpd intrvw	Male	Aust/WA	University	Chem
#64	Faxed/hand	Female	NZ	T Trainer/prim	Chem
#65	By e-mail	Male	USA	University	Gen Chem
#66	By e-mail	Male	USA	University	Chem Ed
#67	Fax/typed	Male	Aust/Q	Teacher	Chem
#68	E-mail	Female	USA P/Rico	University	Gen Chem
#69	Written	Female	Norway	Teacher	Chem
#70	Disc	Female	Aust/NT	Teacher	Int Sci
#71	Typed	Male	Solomon I	Teacher/Curr	Chem/Phys
#72	E-Mail/attach	Male	Nethlands	Researcher	Chem Ed
#73	Written	Male	NZ	University	Chem Ed
#74	E-mail	Female	Brazil	University	Chem Ed
#75	Typed	Male	W. Samoa	Curric Dev sec	Chem/Bio
#76	E-Mail	Female	S. Africa	Teacher Tr	Phys Edn
#77	E-Mail	Male	Thailand	University	Chem
#78	Written	Male	Aust/NT	Govt/Ind	Chem
#79	Disc	Male	Aust/NT	University	Chem/Ab Ed
#80	E-Mail/atach	Male	Hong Kong	University	Chem/PhD

Countries from which completed received.

Argentina	1
Australia	23
Botswana	1
Brazil	1
Canada	2
Czeck Republic	1
Germany	1
Hong Kong	1
Jamaica	1
Mexico	1
Netherlands	1
New Zealand	3
Norway	2
Papua New Guinea	1
Russia	2
Solomon Islands	1
South Africa	1
Taiwan	1
Thailand	1
UK	11
UK (Scotland)	1
UK(Wales)	1
USA	19
USA (Puerto Rico)	1
Western Samoa	1

* = incomplete

RESPONDENTS
FINAL ALL UK 13 = 16.3%
FINAL ALL USA 20 = 25%
FINAL AUSTRALIA 23 = 28.8%
FINAL ALL OTHERS 24 = 30%
MALE/ FEMALE 66/14 = 82.5%/ 17.5%

RESPONDENT'S PROFESSION (These totals are only approximate)
Teaching 22/80 = 28%
Teacher education 21/80 = 26%
University lecturers pure science 33/80= 41%
Others (industry/ research)4/80 =5%
RESPONDENT'S TEACHING SUBJECT
Very largely chemistry with physicists/ historians of science being the biggest subgroups at 5% or less each.

APPENDIX 3

PHYSICAL AND CHEMICAL CHANGE: AN INFORMATION SHEET

This sheet and the questions that follow is for colleagues who are:-

University academics who are lecturing in University Science /Engineering Faculties in chemistry, physics or other science disciplines.

Science educators who are lecturing in University Faculties of Education or Teachers' Colleges.

Science teachers who are teaching primary or secondary science.

Historians of Science/ Chemistry

Authors of science text books.

Or Scientists who combine more than one of the above roles

Those being interviewed are people, who have expert knowledge in all or part of this area.

INTRODUCTION

This information sheet is intended to provide the reader with background information without attempting to influence respondents. I intend to ask respondents questions verbally and record the answers. Alternatively where distance prevents this approach, I will simply ask colleagues to reply in the form of a letter on those areas that interest them. This method should provide significant information in the form of opinion, anecdote and fact about the concept of "physical and chemical change", which is a small part of the science curriculum. Prior to conducting this interview, I have already carried out research in the area; so in the interviews I will try using supplementary questions to keep the interviews from retracing old ground.

Questions relate to opinion, experience and anecdote. Question topics relate to the areas entitled General, History, Personal History, Definition, Teaching, Broader aspects about teaching, Section for textbook authors.

The questions are completely open ended, so if you have other information about "physical and chemical change" that I have not asked, please feel free to include the point in the discussion or the letter to express your views. I will feel free to use views expressed as a part of my thesis and to summarise and categorise such views in groupings. However the data is qualitative rather than quantitative, so I do not expect to come to specific conclusions, rather I expect there to be a range of views, which should indicate what professional opinion is on the topic.

I will nonetheless be interested in some overall view of whether the concept of physical and chemical change has a future in the teaching of science or whether it should be abandoned without further delay. I am also seeking a personal reflective and even anecdotal style of response as I believe that my thesis relates to factors additional to pure science. Whether responding by interview or letter please feel free not to answer questions in a whole area or individual questions.

INFORMATION ABOUT PHYSICAL AND CHEMICAL CHANGE.: SECTION A.
A COMPARISON OF PHYSICAL AND CHEMICAL CHANGES - A TRADITIONAL WAY OF TEACHING.

The table below may have formed the basis of a typical introductory lesson in chemistry some years ago. The teacher would have put the heading "physical and chemical change" on the black-board and would have completed the table as follows:

PHYSICAL CHANGE	CHEMICAL CHANGE
No substance formed or destroyed	Substances changed-New substance formed
No change in weight	Change in weight
Reverse change easy	Reverse change difficult
No energy produced although energ 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 pupils would have copied down the heading and the table. The teacher may well have boiled some water, melted some ice, or torn up some paper into little pieces, as examples of physical change. As examples of chemical change the teacher may have burnt some paper, struck a match, heated iron filings and sulphur, or ignited some magnesium. Each of the criteria would be carefully looked at, with a more thorough teacher actually weighing the products and reactants of each reaction. There might well have been some class discussion to elicit further examples. The teacher would have given more explanation, which might be summarised on the board as further notes. The teacher would round off by setting some examples from the textbook and return to the staffroom satisfied that the pupils had received a thorough grounding in the important concept of physical and chemical change. I will ask for comments on this approach.

SECTION B. AN OPINION ABOUT PHYSICAL AND CHEMICAL CHANGE

The reaction of a practicing chemist from the United Kingdom (Satchell, 1982) when he learnt that his son was being taught in the way described above was to write the following.

"My son recently showed me his O - level chemistry textbook. He finds some of its introductory statements and definitions confusing. The book certainly surprised me. The early sections contain statements that are woolly or wrong by present day standards; indeed, wrong in terms of facts given later in the book. Some difficulties arise because the authors introduce chemistry by distinguishing between chemical and physical processes....... It is only after these topics have been covered that sections dealing with atoms and molecules are given. ....
............Another example of needless early inaccuracy concerns the distinctions made between physical and chemical changes. For chemical changes we learn that:
(i) A new kind of matter is always formed.
(ii)the change is not easily reversed.
(iii) a large heat change is usual.
(iv) the products have different masses from the reactants.
The opposite situations are said to apply to physical changes. These criteria do not bear serious examination! Why bother with them in books at this level? The properties of substances and the various processes relevant to Chemistry can be fully treated without labeling them physical and chemical."

Satchell's complaints aroused considerable controversy and convinced me that there is interesting and worthwhile information to be obtained from the views of people who use chemistry differently in their daily lives such as those currently being surveyed.

In searching through science/chemical journals I have found about 3 other instances of very strong opinions being expressed about physical and chemical change. This makes me believe that there are reasons other than scientific reasons for the use of the concept of "physical and chemical change"

REFERENCES

Satchell, D.P.N. (1982). Beginning O- Level chemistry, Chemistry in Britain, March, p.161

SECTION C. ALTERNATIVE HYPOTHESES

(This section will be needed in answering question 10)

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.

SECTION D. EXPLANATION OF MACRO/MICRO PHENOMENA

(This section relates to question 32)

The problem was stated by the authors of the Chemical Bond Approach Project (CBA, 1964) who carefully explain how the different opinions, that people express on this topic, can be reconciled.

"In chemical change the reactants and products contain the same atoms but differ in the pattern in which the atoms are arranged. The definition of a chemical change in terms of atomic theory differs from the earlier operational definition of chemical change in terms of observable properties.

Such a conceptual definition tells you what to think about rather than what to do. Chemical change may thus be given either an operational or a conceptual definition. These two definitions suggest that changes in properties are associated with changes in arrangement of atoms. It is important to note that the two kinds of definitions will sometimes refer to a given change in the same way and sometimes not. When liquid water changed to steam, the operational definition labeled this as a physical rather than a chemical change. Comparison of the arrangement of the molecules in liquid water suggests that at least this physical change does not differ in principle from the changes ordinarily called chemical."

REFERENCE.

CBA (1964). Chemical systems (Chemical Bond Approach Project), St Louis, McGraw-Hill Book Company.

APPENDIX 4

FULL QUESTIONAIRE: INTERVIEW PROTOCOL OR BASIS FOR WRITTEN RESPONSE

STATE the name of the person being interviewed, the time and date and place

GENERAL QUESTIONS

1. What is your highest qualification ?
2 Are you a trained teacher?
3. Where do or did you work?
4. Which broad area of chemistry/physics/other is your main teaching and research area? e.g. inorganic chemistry.
5. Would you class yourself as an experimental or a theoretical scientist(in as far as these broad definitions are meaningful)?
6. If you are a science educator, which of the sciences are most interested in teaching?

HISTORY SECTION

7 Would you associate the name of any particular scientist with the concept of physical and chemical change in the same sort of way that you might associate Darwin's name with evolutionary theory?

8. (i) Are you broadly sympathetic with the idea of using historical material in the teaching of school chemistry?(ii) Or should teachers concentrate on teaching the facts and principles of chemistry divorced from their historical context?

9. Do you have any view about the gradual change in the usage of the words "cohesion and chemical affinity" in the first half of the nineteenth century gradually changing to the words "physical and chemical change" in the latter part of the nineteenth century. Views about reasons for this change, people or events that may have influenced the change or precise timing would be helpful. My research is currently showing differences between France, UK, and USA. I would be interested in comments.

10. Do you consider that any of the four hypotheses (Section C in the information sheet) account for either the origins or the longevity of the concept of "physical and chemical change"?

PERSONAL HISTORY: LOOKING BACK WHILST YOU WERE A STUDENT AT SCHOOL.

I realise that your own school days may be some time ago, but I feel that taken over a large group of people, details of personal experience can give valuable insights into what parts of school science, if any, influence people's lives

11 Looking back on your own school science generally can you recount the most memorable lesson that you remember? (It may have been humorous/sad/ enjoyable/exciting etc).

12. Can you recollect the topic of physical and chemical change being taught at school for the first time? Please give an account of your recollections. In particular can you remember any lesson about physical and chemical change that was humorous, sad, enjoyable or exciting

13 Can you remember if any particular teacher or scientific topic interested you enough to help you decide to choose science as a career.

14. Do you think that the concept the topic of physical and chemical change is of any value in thinking about the major world issues that relate to science generally and to chemistry, in particular? Issues like greenhouse effect, lead in petrol, the ozone layer etc). Please give an account of how you believe that the concept of physical and chemical change has influenced your thinking?

CLARIFICATION OF THE DEFINITION OF PHYSICAL AND CHEMICAL CHANGE

15. In your view is the definition of physical and chemical change (as indicated in the first part of the paper) a clear definition scientifically? If your answer is NO, please indicate how you would improve the definition of physical and chemical change.

16. Let us now look at the stated criteria as found in school textbooks for physical and chemical change as shown in Table 1, and consider them one at a time. Are there scientific, logical/practical or pedagogic problems with each part of the definition?

17. Can you summarise the scientific, logical / practical or pedagogic problems with the joint definitions of physical and chemical change taken as a whole?

18. Can you give any practical examples of changes that cause difficulties in the classification of physical and chemical change?

19. Do you consider it necessary to oppose the words "physical and chemical" in contexts other than "physical and chemical" change? e.g. "physical and chemical" properties in chemistry or "physical and chemical" weathering in geology. If so, how would you define "physical and chemical" without using the concept of physical and chemical change.

THE TEACHING OF PHYSICAL AND CHEMICAL CHANGE IN SCHOOLS

20. Do you think that the topic of physical and chemical change should be taught in schools at all? If you think that the topic of physical and chemical change should be taught in schools, at what grade levels should it be taught?

21. If you think that the topic of physical and chemical change should be taught in schools, please indicate how you think it might be taught ?

22. Should the way that physical and chemical change is taught in schools be in line with the idea of a spiral curriculum? (That means teaching important curriculum topics more than once at increasingly sophisticated levels of understanding)

23. I do not think that anyone suggests that teaching chemical reactions and change of state should be eliminated from the curriculum. Some people do object to physical and chemical change being taught in opposition to one another as in the table on p.2? Do you consider that these topics should be taught separately, perhaps giving examples of chemical reactions in one part of the syllabus and an explanation of change of state in another part of the syllabus or that they should be taught in opposition to each other?

24. From your experience, do you think that students generally find the concept of physical and chemical change easy or difficult to understand?

25. If students are taught the topic of physical and chemical change in a fairly traditional way, do you think that they should be able to categorise changes into those that are physical changes and those that are chemical changes with a reasonable degree of accuracy? Is it a useful skill for them to have? Are there any particular changes that give you consider might give students difficulty in categorising correctly?

26. In the science/ chemistry curriculum at a school what related topics should be taught before physical and chemical change and what topics should be taught after physical and chemical change?

27. Should students do any practical work themselves when they are taught about physical and chemical change? If so please mention some suitable experiments.

28. Should students observe any demonstrations when they are taught about physical and chemical change? If so please suggest some demonstrations.

29. Do you know of any films, slides, videos or other teaching aids that are relevant when students are taught about physical and chemical change? If so please give details.

30 Do you think that the teaching of physical and chemical change should be related to any particular relevant application, everyday use or ethical problem? If so please give details.

31. Satchell (1982)made some comments about the teaching of physical and chemical change at a junior secondary level. Do you agree/ disagree with Satchell? Why?
“These criteria do not bear serious examination! Why bother with them in books at this level? The properties of substances and the various processes relevant to Chemistry can be fully treated without labeling them physical and chemical."

32. Sometimes we consider matter in terms of its ‘bulk properties’ (a macro scale approach), whereas on other occasions we consider matter in terms of the individual atoms or molecules (a micro scale approach) that make it up. When we consider changes on a macro scale we may consider them to be one sort of change; when we consider them on a micro scale we may consider them to be another sort of change. (A fuller explanation in Section D of the information sheet)

Do you have any further comment on this explanation?

MORE PEDAGOGY AND BOUNDARIES BETWEEN PHYSICS AND CHEMISTRY

I was able to find evidence that some researchers who interpret their data as stating that the concept of physical and chemical change should not be taught to children below the age of eleven and I was able to find evidence contrary evidence that the first UK National curriculum recommends that the concept of physical and chemical change should be taught to children at about the age of six years.

32. What are your views as to the age when students should be taught the concept of physical and chemical change and why?

33An objection to teaching physical and chemical change has been that it would interfere with students understanding of thermodynamics at a later stage. this view was expressed by Nyhom & Halliwell in the planning of Nuffield Chemistry. Do you agree or disagree with this view?

34 Do you consider that in boundaries between the separate sciences (and in this instance the boundary between chemistry and physics) should be clearly spelt out to students at a junior high school level. Alternatively do you feel that this hinders the integration of the sciences?

35 Do you consider that teaching the concept of physical and chemical change helps to clarify the boundary between chemistry and physics?

36 In your view, is one of the reasons that chemists and physicists continue teaching the concept of physical and chemical change is that they believe that it helps to clarify the boundary between chemistry and physics for junior high school students?

37. In your view is one of the reasons that chemists, in particular, continue teaching the concept of physical and chemical change to junior high school students is that they believe that it is an interesting and exciting area and that it will attract students to do chemistry later?

SECTION FOR TEXT BOOK AUTHORS ONLY (THIS MEANS YOU ARE THE AUTHOR OR PART AUTHOR OF A SCIENCE / PHYSICAL SCIENCE / CHEMISTRY

TEXT BOOK).

38 Please complete this section for one named text book that you authored/ co-authored.

39 Did you include a section on physical / chemical change in your text book?

40. In your book, are physical and chemical change taught in opposition to one another as in the table on p.2? Or are the topics taught separately, perhaps giving examples of chemical reaction in one part of the book and an explanation of change of state in another part of the book?

41 Do you have any comments about writing the section on physical and chemical change, perhaps on the choice of examples of each, the position in the book of this section, the length of the section, the choice of definition of physical and chemical change for this section or any other aspect of writing about physical and chemical change?

THAT IS ALL! THANK YOU FOR YOUR HELP!

APPENDIX 5 STANDARD LETTER

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15/2/ 96

QUESTIONNAIRE QUERY ON PHYSICAL AND CHEMICAL CHANGE

Dear -

Most of those to whom I am writing are people who have written on CHEMED-L Listserver in the last couple of months and who obviously have a keen interest in chemistry. A few of those to whom I am writing have discussed some topic with me over the internet at some time in the past. Most of those to whom I am writing will not know me personally at all.

I am anxious not to give any offence by sending out the questionnaire on a random basis, so this letter is to find out if you would be able to answer a questionnaire for me or not.

I expect the total number of responses to be comparatively small, as my aim is to seek expert knowledge from experienced professionals worldwide. I have already given out some questionnaires locally and some at conferences etc. I hope to obtain a balance of opinion by including respondents of either gender from a variety of countries, some in teaching chemistry, some in teaching teachers science/ chemistry and some from the history of science etc.

My purpose in sending this letter is to ask you if you would be prepared to complete a questionnaire on physical and chemical change for me. The questionnaire is lengthy - 5 pages of explanation and 5 pages of questions (that is 37 questions + another 4 if anyone is a text book author). My estimate is that it could take 2 hours to complete.

The questionnaire is about physical and chemical change, the history of the expression, personal recollections of being taught or teaching physical and chemical change, views on some hypotheses I have thought out to explain the longevity of the concept, the age of children to whom it should be taught, how it should be taught, and the boundaries between physics and chemistry.

I realise that for busy people, there are always many things to do and that filling in questionnaires tends not to come very high on most people's priority list, but I would be most grateful if you could find time to complete this questionnaire.

I see this questionnaire as a way of sampling (if only in a small way) what the opinion of chemistry teachers, chemical educators and other scientists is worldwide, with regard to the way that physical and chemical change should be taught in schools. Respondents can omit questions if they think them to be repetitive or irrelevant. They may add questions where they think I should have asked them, but have failed to do so.

The questionnaire can be answered by mail/ e-mail / or by sending a tape recording of your answers: If sending by snail-mail answers can be handwritten or typed just against a number to represent the number of the question. To me, it is the knowledge/ expert opinion that is important rather than the way of expressing it.

If you are prepared to complete the questionnaire, just send me an e-mail message requesting it. I would then send you the questionnaire by e-mail with a request that you complete it within the next month.

If you don't think you would have time to complete the questionnaire, please send me an e-mail message saying so.

Thank you for your help and consideration.

Yours sincerely,

BILL PALMER