Educational research

Some aspects of students' understanding of a representational model of the particulate nature of matter in chemistry in three different countries

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Abstract: This preliminary study is part of a cross-cultural study that investigates students' understanding of a particulate model used for relating submicroscopic entities and processes to macroscopic events in chemistry. The study initially involved some selected secondary school science students in Nigeria (Grade 10; n = 224) and in Japan (Grade 12; n = 72) and was later repeated with first year preservice university science teachers (n = 27) in South Africa. Subjects were presented with several test items in which they were required to use the particle model to infer the macroscopic chemical events they are meant to depict. The results show that for many of the subjects across the three countries, making the association between submicroscopic models and macroscopic events was problematic and not entirely straightforward. Intuitive misunderstandings abounded. One implication of the findings so far for chemistry education is that students are not always able to display consistent reasoning about the particulate nature of matter unless they have appropriate representational model on which to base their thinking. The knowledge of their conceptual misunderstandings, however, provides a basis for a good teaching point and for changing pedagogical approaches. [*Chem. Educ. Res. Pract.*, 2006, **7** (4), 226-239]

Keywords: Particulate model, microscopic processes, macroscopic changes, chemical education, conceptual change, representational model

Introduction

Education implies that what is taught becomes sensible to the learner. However, much of what takes place in the classroom today in the name of chemical education is not necessarily like that. The task of teaching students chemistry concepts meaningfully is sometimes rather complicated, and is too often not fulfilled. It often seems that 'paying attention to' and 'understanding' are skills required of the learner exclusively. A student's difficulty in comprehending certain concepts is likely to be attributable to his or her failure to listen to and to understand what the teacher or textbook has to say. This preliminary study is about gaining some insight into students' conceptual difficulties if any, with particulate models used to represent changes taking place at the submicroscopic level in chemistry.

One factor that is related to students' conceptual difficulties in chemistry problem solving is what Onwu (1980a, 1980b, 2002) has described as an inadequate mental representation of the chemical reality being considered or thought of; in contrast to what Simon and Simon (1978) have referred to in physics as 'physical intuition' of the expert physics problem solver. Physical intuition, accordingly, is construed as having an adequate mental representation of the problem situation, which allows for successful solution. The major reason why students are unable to solve problems in chemistry is that in most cases the chemical concepts on which the problems are based do not make sense to them. In studying the ways experienced problem solvers and novice problem solvers went about solving stoichiometric mole-type problems, Onwu (1980b, 2002) noted that the difference in skill between the two groups is that the experienced problem solvers tend to move from the problem statement to a mental representation of the chemical situation, which then guides the rapid retrieval of the appropriate learned rules to solve the problem. On the other hand, the inexperienced learners appear to go directly from the problem statement to the learned rules, searching for the memorised algorithm or algebraic relation needed to get an answer. The novice learners do not appear consciously to internalise the chemical meaning of the task. Instead, they are likely to approach the problem with strategies that are tied to the salient or surface features of the chemical task at the expense of the task goal (Onwu 2002).

What is of interest is precisely what steps are required to help students move from the algebraic (algorithmic) stage to the meaningful stage in chemistry. It seems fair to comment that many of the existing pedagogical practices in our chemistry classrooms do little to promote that shift. In line with what Lederman, Gess-Newsome, and Latz (1994) have suggested, we need to gain more insights into students' conceptions and learning difficulties with regards to specific topics in chemistry, so as to make chemistry more meaningful and accessible to more and more students.

In this study, the focus is on an important topic in chemistry teaching, namely, the use of the particulate nature of matter to relate macroscopic phenomena (e.g. physical and chemical processes, properties of substances) to submicroscopic particles (e.g. atoms, molecules, ions). Although there have been several studies of secondary students' conceptions in this area (Harrison and Treagust, 2002), according to Justi and Gilbert (2002), little is known about pre-service science teachers' knowledge of this important theoretical construct and how it is developed. Current research (Harrison, 2000) shows that secondary school science teachers also hold some of the incorrect alternative conceptions held by students. The recent study by De Jong et al., (2005) of the pedagogical content knowledge of pre-service postgraduate chemistry teachers in the use of particle models of teaching, underscores the ongoing interest in the teaching of the particulate nature of matter. However, very few studies have investigated students' ability to relate observable phenomena to submicroscopic entities using pictorial representations of the particle model.

In recent times, Harrison and Treagust (2002) have argued for more research at senior and post-secondary level that would inform practice, as to how a more enriching and perhaps slower development of the concepts of the particulate nature of matter should be introduced so that students can digest and assimilate the ideas with attention to common misconceptions. Such research has become necessary in the South African context because of the growing recognition or awareness that post-matriculation students, who gain entry into chemistry and/or science teacher education departments, still hold incorrect and/or over simplistic conceptions of the particulate nature of matter. For the chemistry lecturer, however, difficulties occur when these spontaneous ideas or alternative views held by students appear to compete or interfere with the scientific understanding that the lecturer is trying to put across. Particle ideas are fundamental to all physical and chemical explanations.

In what follows we discuss some of the available research on chemistry students' intuitive conceptions of the particle theory, and then present an analysis of students' responses to several test items on the particulate nature of matter that we have used in an ongoing cross-cultural study.

Background and the problem

In chemistry, the idea that all substances are composed of small indivisible particles called atoms, molecules and ions is generally accepted. From an early age students, particularly in the Western world, are familiar with stylised atoms and molecules that are frequently used as logo for many of the popular science TV programmes (Johnston, 1990). The children have also been exposed into the mysteries of science, of atoms and molecules by what they read in comics, storybooks and textbooks, by what they are taught and experience in class through watching particle simulations in audio-visual teaching aids. Thus, children at an early stage in well-resourced environments become aware of atoms and molecules well before particle theory is taught in school (Lee et al., 1993). But this is where any similarity between scientific understanding and learner preconceptions ends.

It is well known that the concepts of atomic and molecular structure are very difficult for the students. Tsaparlis (1997) has shown this by analysing the concepts from various perspectives of science education. Taber and Watts (2000) analysed students' explanations about aspects of chemical structure and bonding. In addition, various studies (e.g. Johnstone, 1991; Cachapuz and Martin 1993; Albanese and Vicenti, 1997; Maskill et al., 1997; Johnson, 1998; Gabel, 1999) have shown that while many students are enthused by descriptive chemistry such as performing eye-catching chemistry experiments, and while it is easy to capture their interest at that macroscopic level, sustaining this interest conceptually at the submicroscopic and symbolic levels is a real pedagogical challenge. Some of these studies have provided useful insights into how students' views, beliefs and preconceptions of the particulate nature of matter differ. For example, Nakhleh (1992) reported results "*that over half the students from junior high school to senior high to university held concepts that were consonant with a perception of matter as a continuous medium, rather than as an aggregation of particles*" (p. 192). But of course, the accepted scientific view is ontologically very different (de Vos and Verdonk, 1996). Students consistently and erroneously hold that matter is continuous and attribute macroscopic properties of matter to its submicroscopic particles (Albanese and Vicenti, 1997; Johnson, 1998; Harrison and Treagust, 2002). The contrasting idea that molecules are in substances, rather than that substances are made up of molecules is equally common.

Other studies reported (e.g. Krnel et al., 1998) that students use the macroscopic properties of a substance to infer its particle properties. In other words they think or reason from that which is visible (i.e. large), to that which is invisible (i.e. small). For example, "*molecules in ice are thought to be heavier than those in liquid, with molecules of water vapour being the lightest*" (Krnel et al., 1998, p. 265). Beginning students intuitively believe that copper atoms are red-brown because copper is red, or that chlorine atoms are green because it is a greenish yellow gas (Ingham and Gilbert, 1991). But the scientific model reasons exactly the opposite way in which particle action is used to infer or explain processes. The various intuitive misconceptions held by students have been attributed to their inexperience in the use of scientific models, lack of appropriate or adequate mental representation, and/or their lack of 'intellectual maturity' (Harrison and Treagust, 1996, 2002), which is seen as a maturational factor.

As was indicated earlier on, there is evidence that secondary science/chemistry teachers also hold some of the misconceptions held by their students. Due to a lack of topic-specific pedagogical content knowledge for teaching certain chemistry topics effectively, many teachers are constrained to plan and teach from textbooks, which have already been shown to be a veritable source of alternate conceptions (Harrison, 2001). Given the dominant role of textbooks in our schools, and the way school chemistry textbooks in particular present the particle theory (de Berg and Treagust, 1993), it has been suggested and indeed acknowledged that many of these textbooks contain a number of cognitive gaps that are likely to impact on students' developing ideas. For instance, the textbooks rarely address the limitations and the history of the development of particle models; hence these particle models are often presented as rhetoric, or as final versions of our knowledge (de Jong et al., 2005). Furthermore, few secondary chemistry textbooks include exercises that require students to actively use particle models for relating observable phenomena to submicroscopic entities (Erduran, 2001).

In their comprehensive discourse of the particulate nature of matter and the challenges in understanding the submicroscopic world, Harrison and Treagust (2002) make the point that there is a tension between teaching macroscopic chemistry, which is generally hands on and viewed by students as interesting, and the difficulties of explaining macroscopic changes in terms of the behaviour of submicroscopic particles. Part of the tension has been ascribed to how and when to deal with those three worlds in chemistry teaching that characterise chemistry: namely, the worlds of symbolic representations (formulas and chemical equations), macroscopic events (actual experiments) and submicroscopic models (atoms and molecules etc), and whether or not the particulate model is best explained at the macroscopic, submicroscopic, and/or symbolic level (Johnstone 1991; Gabel et al., 1992). The conceptual demands of switching between models and phenomena can be daunting (Andersson, 1990). The experienced chemist is comfortable in all three worlds and can easily move from one to the other. The novice learner is comfortable in none of these worlds and has difficulty relating one to the other.

Interestingly enough, the three-worlds-view of chemistry dates back to Dalton (Nash, 1966). Dalton, according to Nash, sought some superficial way to represent what was happening at the subatomic level when new substances are formed. And so he invented the symbols that enabled him to manipulate atoms on paper and in his thought experiments. Similarly, in order to assist students with this way of visualising submicroscopic entities and processes, textbooks have used various kinds of approximation of physical models, analogies of pictorial representations, which match the students' levels of conceptual sophistication. At least so we think. Harrison and Treagust (1996(now included) in their investigation of students' (grades 8-10) understanding of models of atoms and molecules found that most students preferred models of atoms and molecules that "*depict these entities as discrete, concrete structures* " (p. 532). Ingham and Gilbert (1991) in their study have obtained similar results.

Although many meanings are attached to the notion of models, generally speaking a model in science may be defined as a non-unique, partial representation of a target, focusing on specific aspects of it, whereas other aspects of the target are deliberately excluded (Ingham and Gilbert, 1991). A 'target' as used here refers to a system, an object, a substance, or a process (de Jong et al., 2005). This is the overall sense in which our pictorial representation of the particulate nature of matter (the particle model) has been used in this study.

Particle models have become very important in chemistry (Justi and Gilbert, 2002), and that is why the interest of the present study is with the investigation of how students' understanding and use of a schematic (pictorial) representation of the particle model contribute to the cognitive and/or communication gap if any, between the novice learner and the chemistry teacher. We need more information on what conceptual changes are needed to be able to fill any cognitive gaps on the particulate nature of matter. To this end, it would be useful to identify students' existing ideas on abstract symbolism as additional evidence for helping to do just that. The interest of the preliminary study is with providing an opportunity for students to think and reason with particle models for visualising abstract macroscopic processes and submicroscopic entities. Specifically, we wish to determine whether the participating subjects from across the different cultures have common or radically different ways of looking at the relationship between subatomic particles and macroscopic properties as depicted.

Subjects

The subjects of the study come from the three countries of Japan, Nigeria and South Africa. These groups of students have been used for this cross-cultural study, partly because the three countries have certain educational characteristics in common, which might provide a useful basis for comparison, and partly because of the presumed cultural differences.

Each country has a uniform national science curriculum of high standard, and time invested in formal courses of study. The science curricula are supported by ministry directives, instructional guides, school inspections and recommended textbooks. The recommended textbooks of all three countries at the time of this investigation were similar in terms of content coverage, scope and approach. In Japan and Nigeria chemistry and physics are offered separately at the senior secondary level (Grades 10-12), while in South Africa science is taught as a single integrated physical science (chemistry and physics) subject. The chemistry component of the science syllabuses is similar for the three countries. With regards to the idea of the particulate nature of matter, this topic is encountered or introduced more or less about the same time, early in the syllabus. All three countries have a matriculation examination at Grade 12, which constitutes an exit point within the school system. In Japan and South Africa this public examination is taken at the end of Grade 12. In Nigeria, this is taken at the end of a 3-year senior secondary (SSI-SSIII) level system, which is equivalent to Grades 10-12. The extent to which the school leaving matriculation science examinations of the three countries are adjudged to be largely memory-oriented, their science curricula assessment approach may be seen as comparable.

The Nigerian subjects at the time of the study had just completed SSI, equivalent to grade 10, and about to enter SSII (Grade 11). The first year South African university science teacher students used as subjects were fresh entrants to the university and had just completed Grade 12 (3 months earlier) and obtained their school leaving senior certificate. They had had little or no instructional input from university lecturers at the time of the study. Arguably, their knowledge level was still at secondary level. The Japanese students were in the first term of their Grade 12 science class. All three population groups had covered the relevant scientific ideas about the particle nature of matter, and the assumption was that their content knowledge with regards to the demands of the test items should not to be very different. As expected, linguistic, institutional and cultural differences will exist among the groups.

The group sample sizes vary widely, and this was largely due to availability of students that fit into the categories of subjects we wanted to study. Since the focus of the study was on describing the nature of students' qualitative thinking and reasoning about the submicroscopic world in chemistry, and the fact that the statistics used for comparative analysis was simply a descriptive one of frequency, sample size differences do not necessarily pose a validity problem for a study of this nature.

We now examine the comparative responses to a set of multiple-choice type test items, together with reasons for response, by the subjects of the study. The subjects comprised, South African university first year science student teachers just enrolled for the Bachelor of Education degree programme (n = 27), Japanese Grade 12 science students from three 'super science schools' (n = 72) in Naruto prefecture, and Nigerian senior secondary science students (SSI/Grade 10, n = 224) selected from 10 secondary schools in a municipality. All the subjects were from intact classes.

Subjects were presented with the following test items, in which they were asked to select one option from the multiple choice-type questions and to provide reasons for their choice.

The results were analysed in two stages:

1. The number (in percentage) of responses for each of the options was determined. The correct option is underlined.
2. The reasons for choice were analysed and summarised. They are given in italics.

The main reasons for the choice of answers are given in actual quotes for ease of reference.

Test Instrument

Refer to the following Figures (1-7) in answering questions 1–7

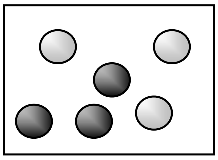
Figure 1

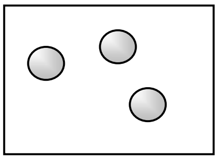
Figure 2

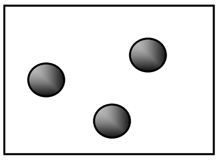
Figure 3

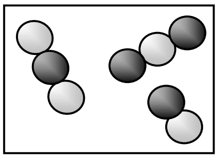
Figure 4

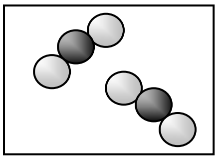
Figure 5

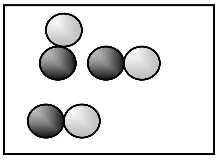
Figure 6

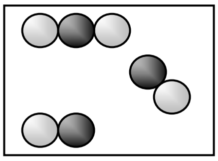
Figure 7

In the Figures the symbols represent the following:

<table>
<tr><th colspan="3">Symbol</th><th>Represent the following</th></tr>
<tr><td colspan="3">○</td><td>Atoms of one kind</td></tr>
<tr><td colspan="3">●</td><td>Atoms of another kind</td></tr>
<tr><td>●○●</td><td>○●○</td><td>○●</td><td>Molecules formed when these atoms bind to one another.</td></tr>
</table>

Questions

Table 1. Which Figures represent pure substances?

(a) 2 and 3 (b) 3 and 4 (c) 2, 3, 4 and 7 (d) 1, 3, 5 and 6 (e) 2, 3, 5 and 6

No. of SS	Student Group	(a)	(b)	(c)	(d)	(e)	No choice
27	1st Year pre-service SA teachers	88%	0%	0%	8%	4%	
72	Japanese students (Grade 12)	83%	11%	2%	0%	4%	
224	Nigerian students (Grade 10)	66%	10%	6%	0%	16%	2%

This question is about atoms and molecules, the basic conceptual starting point for understanding particle model. There are two decision rules to be made: Is it pure? And is it a substance? The rule that 'pure' means 'one kind of particle' seems to have been understood and applied. For example, pure is viewed as *"only atoms of the same kind"*. But the rule for a 'substance' which should include everything around us, both elements and compounds, appears not to have been understood or considered. This would account for the very high percentage of all respondents, 66-88% (see Table 1) choosing option (a), an attractive distracter depicting only atoms of the same kind. When the reasons of choice were analysed, a pure substance is interpreted as *"pure substance has only one type of atom"; "pure substances are elements not mixed with anything else",* and pure substances are *"atoms of the same kind"*. The Japanese students gave similar responses mentioning as their reason for the choice of option (a) as, *"only one kind of atom is found", "atoms are not bonding"* and *"each box shows a set of atoms of a single kind"; "not combined with other atoms"*. In other words, a majority of the students interpreted pure substances as elements only, and not as compounds as well, having more than one type of atom in a definite molecular arrangement. In the very few cases (4%) where the correct option (e) was chosen, the students understood that both atoms and molecules are included: Thus, they reason pure substances "*are composed of molecules, compounds or atoms of a single kind*"

Table 2: Which Figures represent pure compounds?

(a) 2 and 3 (b) 5 and 6 (c) 4 and 6 (d) 1 and 3 (e) 4 and 7

No. of SS	Student Group	(a)	(b)	(c)	(d)	(e)	No choice
27	1st Year preservice SA teachers	15%	63%	4%	4%	11%	4%
72	Japanese students (Grade 12)	7%	72%	4%	4%	13%	
224	Nigerian students (Grade 10)	24%	43%	6%	12%	15%	

Two decision rules are required here. Is it pure? And is it a compound? (that is, composed of more than one element of definite composition)? The reasons given for the correct choice (b), are mostly "*the same number of atoms of definite combination/composition", "molecules of the same kind"; * or " *pure compounds are made up of the same molecules as arranged in definite ratio",* which indicate understanding.

About 40% of the student teachers did not choose the correct answer. Those subjects who selected the incorrect options (a) and (e) appear to be totally at a loss at this point, as they were unable to distinguish between elements and compounds or between mixtures and pure substances respectively as represented. Again the term pure substance seems to have presented a problem. The reasons given by respondents for choice (a) indicate that they only regard substances as pure when *"the same kind of atoms are grouped together in the Figure or box",* or *"any combination in the Figure is of the same kind of atoms"*. The question that comes to mind is: How do they understand the term compound? The students who selected option (e) reasoned along the lines that the "*atoms, that is the circles are sticking together to form compounds"; "compounds are mixtures formed after the combination of two molecules*" apparently without taking into account the qualifying term pure.

Option (c) includes a mixture and a pure compound, figs 4 and 6 respectively. In each of those Figures there is the same number of each type of atom. The equal number of atoms (see fig. 4) seems to be the basis for the choice of option (c). The reasons are as follows, "*the* *numbers of circle shaded and unshaded are equal", "there is equal number of atoms to form a compound"* and *"all atoms have equal ratios"* so they represent pure compounds. The fact that a considerable percentage (11-15%) of the science students did not realise that changes in the arrangement of atoms and molecules in definite composition as represented by the circles (unshaded, shaded and touching) had something to do with whether or not it was a pure compound (macroscopic property) or of the same substance is of some concern.

Table 3. Which Figure(s) represents a mixture of compounds?

(a) 1 and 7 (b) 4 only (c) 5 and 7 (d) 4 and 7 (e) 1, 4, and 7

No. of SS	Student Group	(a)	(b)	(c)	(d)	(e)	No choice
27	1st Year pre-service SA teachers	4%	19%	4%	59%	15%	
72	Japanese students (Grade 12)	2%	20%	14%	53%	11%	
224	Nigerian students (Grade 10)	13%	5%	12%	37%	30%	3.0%

Table 4. Which Figure(s) represents a mixture of elements?

(a) 1 only (b) 4 only (c) 1 and 7 (d) 4 and 7 (e) 7 only

No. of SS	Student Group	(a)	(b)	(c)	(d)	(e)	No choice
27	1st Year pre-service SA teachers	78%	0%	7%	11%	4%	
72	Japanese students (Grade 12)	76%	12%	3%	0%	9%	
224	Nigerian students (Grade 10)	53%	4%	23%	10%	10%	

Table 5. Which Figure(s) represents a mixture?

(a) 1 only (b) 4 only (c) 5 and 6 (d) 1, 6 and 7 (e) 1, 4, and 7

No. of SS	Student Group	(a)	(b)	(c)	(d)	(e)	No choice
27	1st Year pre-service SA teachers	37%	4%	7%	7%	41%	4%
72	Japanese students (Grade 12)	27%	17%	13%	3%	40%	
224	Nigerian students (Grade 10)	7%	33%	22%	14%	24%	

Test items 3, 4 and 5 require using the particle model to identify observable macroscopic functions involving mixtures, mixtures of compounds and elements.

For test item 3, just over 50% of the pre-service and Grade 12 Japanese students and one third of the Grade 10 Nigerian subjects chose the correct option 3(d). The successful subjects understood both what a compound is and a mixture as a combination of two or more substances in which the substances whether as elements or compounds retain their distinct identities. Their explanation for the correct choice is based on the characteristic features of the particle model to explain macroscopic events. As a result they reasoned that *"a mixture of compounds is formed by different kinds of compounds mixed together… formed by the atoms, (shaded and unshaded) circles"*. Those that chose the incorrect options, however, in some cases had difficulty distinguishing between elements and compounds. For example, option 3 (e), was selected by a considerable percentage of students (11-29%). The reasons for the choice were mainly that "*it is a mixture of different elements and compounds*", "*there are different kinds of compounds and elements in the Figures*". The question is: why did they include a mixture of elements when it was not asked? Could it be that they do not appreciate the significance we attach to circles that touch? But the students understood the characteristic features of the particulate model that they were looking at. Yet they chose to include a mixture of elements in their choice. However we suspect that the difficulty here in option 3(e) also involves understanding the difference between a mixture of elements, and a compound composed of those elements.

Students that chose 3(b) (about 20% of the pre-service teachers and Grade 12 Japanese students) also simply selected only one out of the two correct Figures that depicted a mixture of compounds. Whether the difficulty here is as a result of excess demand on information processing capacity (working memory) that is, the maximum amount of items of information an individual can attend to at any one point in time (Onwu, 1980), or one of closure is still not clear. Interestingly enough, those students who selected option 3(b) gave reasons that indicated that they could correctly define a compound or a mixture. For example, reasons for choice include: "*it is a mixture of compounds*", and "*because it [the Figure] has a mixture of every compound in it*". Here we can surmise that they are using the characteristics of the particle model as stated to explain observable macroscopic functions just as the others who chose the correction option 3(d) did. But students who chose item 3(c) appear to have difficulty with the concept of mixture, because that option included Figure 5, which depicts a pure compound and not a mixture. The conceptual misunderstanding is apparent from their reasoning. They reason that option 3(c) represents a mixture of compounds "*because all atoms involved are combined with one another*", and that "*atoms in the Figures 5 and 7 undergo the same kind of bonding-circles are touching*". In other words they are all compounds. Here, unlike the previous category of reasoning, this latter group of students seem to use a substance's macroscopic properties (compounds) to infer or explain what the particles are like or how they work.

With item 4 almost 75% of the preservice and Grade 12 Japanese students and just over 50% of the Nigerian learners had no difficulty relating the particulate model to a definition of element. It is *"a mixture of elements because they are uncombined atoms of different kinds"*. For the 23% of Nigerian students who chose option 4(c), could it mean that the symbolism of theoretical particles (circles) touching at the submicroscopic level holds no meaningful relationship to what may exist at the visible level? Perhaps, the solution to the question, may involve no more than making our abstract symbolism clear, ensuring that students understand the full significance of the symbols.

Item 5 was apparently more difficult for most of the subjects. We are asking the students to use the Figures to think about macroscopic events in terms of submicroscopic changes that take place. Only about 40% of all the respondents had the correct answer when asked to relate a 'mixture' of substances, which includes both a mixture of compounds and a mixture of elements, to the particle model as presented. Whether the difficulty is as a result of excess informational load on processing capacity or working memory as suggested by Case (1978; 1980) and/or due to lack of appropriate mental structure for the chemical situation is not clear. What is clear though is that macroscopic events such as observations of elements, compounds, physical changes, do not tell us the characteristics of the submicroscopic changes that we assume are taking place. The other option with the highest respondents was option (a) (37%, 27%), which indicates a mixture of elements only. Once again the concept of substance is interpreted or assessed on the basis of the schematic symbols as relating to only one kind of constituent atom. For 33% of the Grade 10 Nigerian students, making the distinction between mixtures and mixtures of compounds and then relating those distinctions to the submicroscopic representations (the Figures) was problematic (cf. option 3(e)). The particle model seems new and counter intuitive for the beginning secondary student.

Items 6 and 7 are more conceptually demanding. We are asking the students once again to use a model of particle behaviour to think about and explain macroscopic events or observations such as physical and chemical changes.

Table 6. Which of the following would represent what takes place in a physical change?

a) Starting with particles represented in Figures 2 and 4 and ending with particles represented in Figure 5
b) Starting with particles represented in Figure 1 and ending with particles represented in Figures 2 and 3
c) Starting with particles represented in Figures 2 and 3 and ending with particles represented in Figure 4
d) Starting with particles represented in Figure 7 and ending with particles represented in Figure 1
e) None of the above would represent a physical change.

No. of SS	Student Group	(a)	(b)	(c)	(d)	(e)	No choice
27	1st Year pre-service SA teachers	7%	33%	22%	22%	11%	4%
72	Japanese students (Grade 12)	9%	35%	23%	20%	13%	
224	Nigerian students (Grade 10)	26%	24%	10%	23%	17%	

Table 7: Which of the following would represent what takes place in a chemical change?

a) Starting with particles represented in Figures 2 and 3 and ending with particles represented in Figures 4, 5, 6 and 7
b) Starting with particles represented in Figures 1, 2 and 3 and ending with particles represented in Figures 4, 6 and 7
c) Starting with particles represented in Figure 1 and ending with particles represented in Figures 2 and 3
d) Starting with particles represented in Figure 1, 2 and 3 and ending with particles represented in Figures 4, 5, 6 and 7
e) None of the above would represent a chemical change.

No. of SS	Student Group	(a)	(b)	(c)	(d)	(e)	No choice
27	1st Year preservice SA teachers	41%	11%	7%	15%	7%	19
72	Japanese students (Grade 12)	23%	20%	16%	30%	11%	
224	Nigerian students (Grade 10)	41%	6%	14%	11%	28%	

The comparatively poor results for the respective test items 6 and 7 (involving about 30% success rate for physical change and less than 10% for chemical change processes ref. Tables 6 and 7) need to be further explained. Making the association between the macroscopic event as defined and the submicroscopic model as represented in the Figures requires a great deal of intuition.

In answering item 7, most of the students appear not to have considered stoichiometric factors. Yet they seem to know that chemical changes involve the rearrangement of atoms or molecules. For example, many of the students selected option 7(a) and gave as reason "*because when you start with different elements you end up with a compound*", ... *a chemical change involves a rearrangement of elements to a new substance*"… "*a compound can be separated by chemical change like combustion to form its constituent elements".* Interestingly enough, some of the students' explanations are quite consistent. Thus of the students who gave chemically incorrect explanation for their choice of options in items 6 and 7, did so by the application of what appears to be logically sound thinking based perhaps on their everyday usage and experience of the term 'physical change' as evidenced in these statements: "*a physical change is when we use a magnet to separate a mixture"* and "*it is because you can form carbon dioxide from carbon and oxygen; the combustion of carbon is a chemical change".*

On item 7, we need to point out here that the introduction of stoichiometric considerations for the correct choice 'e', does pose a problem. Nowhere does the test item stipulate that subjects needed to take stoichiometry into account. Seeing that comparatively few subjects chose 'e' as their option, it would seem that the majority did not take stoichiometry into account or simply ignored it. In that case, options 'a', 'b', and 'd' would be considered acceptable, depending upon the reasons proffered for choice of option by the respondent. It is interesting that more than two-thirds of all the respondents (Japanese 73%; South African 67%; Nigerian 66%) selected those options with valid reasons as follows: "*starting with atoms of two kinds (figs. 1, 2 and 3) and ending with particles of several different molecules (figs. 4,5 6 and 7) represents a chemical change without the stoichiometry* " *because when you start with different elements you end up with a compound*"… *a chemical change involves a rearrangement of atoms of different elements to a new substance…".* In arriving at those other acceptable options, it is possible that the subjects might not have been limited by the number of atoms of each kind shown in the Figures. Again, even if stoichiometry had been the required assumption, Figs 2 and 3 leading to 6 should have been an acceptable chemical change and ought to have been included as an option. Offering it might have served to draw the subjects' attention to the possibility of considering stoichiometry. These observations on item 7 have highlighted an aspect of this preliminary study where students' thinking might have been restricted by the nature of the test item.

In spite of the students' formal instruction in chemistry, we could glean from the written answers of those who gave incorrect explanations that their understanding of 'chemical change' or 'physical change' is still based on some category of experience where those terms have come to be associated with specific events, like "*a physical change is when we use a magnet to separate a mixture",* in the context of the students' day-to-day classroom activitiesSome of the subjects think in terms of experiments (macroscopic events) that they previously engaged in to make sense of the particulate or submicroscopic world (cf. Onwu 1996). It is therefore feasible, that even the term 'chemical change' or 'physical change' may be understood in a figurative, experiential or contextual sense. Chemical or physical change is not thought of as some attribute of the particulate nature of matter, or as a principle with some generality; rather it may well mean for many students just a term to be accepted as part of the idealised world of science. Accordingly, Harrison and Treagust (2002) do make the point that a contextual understanding of the utility of chemistry is likely to be of use here, in motivating students to seek fuller explanation of macroscopic phenomena; to go beyond the visible, in a way that is likely to encourage them to seek particle and symbolic representations for chemical phenomena.

Admittedly, this explanation for poor performance is somewhat speculative. The point remains, however, that from a teaching point of view, multiple conceptual changes about representational particle interactions would have to be in place if we are to bridge the gap between the intuitive and the scientific framework, and this may take a long time. Any conceptual change has to be ontological (Chi et al., 1994; Tyson et al., 1997; Harrison and Treagust, 2002) because as evidenced in this study and others (Chi et al., 1994), students tend to use macroscopic properties to infer what the corresponding particles are like, and how they interact, whereas the expert, uses a theory of particle behaviour to explain observable macroscopic characteristics. Clearly these are radically different ways of looking at the relationship between submicroscopic particles and macroscopic properties and therefore demand different approaches for the novice to assure understanding.

Because of the limited sample instead of large scale representative samples or surveys, it is difficult at this stage to try to see whether cultural differences can explain away any differences in performance among the different groups that might help to uncover useful clues that support or impede the teaching of chemistry. But having said that, it is equally revealing that despite the linguistic, cultural and perhaps institutional differences, the conceptual problems encountered by the three groups were similar, involving many consistent, intuitive misunderstandings. Given the Japanese students' apparent advantage in being taught in their mother tongue, the Grade 12 science subjects also struggled in using schematic symbols to assess concepts such as 'pure' 'element' and 'compound' or 'substance'. The source of the difficulty may not necessarily be cultural. We may need to look elsewhere. We need other evidence–based data to be able to intervene. From a constructivist point of view, the much needed conceptual change will most likely be evolutionary rather revolutionary, requiring new instructional strategies that are informed by preliminary findings such as those of this study.

Conclusion

In this preliminary study we have tried to glean from students' responses the difficulty they have in relating the worlds of submicroscopic entities and macroscopic phenomena in chemistry. It is evident that many students found it difficult to imagine macroscopic events microscopically using the particle model. There was, however, remarkable consistency in the ways students from the three participating countries reasoned about the different test items. It was equally obvious that certain misconceptions persisted over the years. Exactly how we can make atoms and molecules 'real' to students is not very clear. We cannot show atoms, and besides the models that we employ are often poor approximations that are often used to portray certain properties which sometimes end up distorting other properties. Secondly, a student's better understanding of the concepts underlying the particulate nature of matter may also be inhibited, precisely because of the teacher's haste to cover "mechanical skills'' and get on with the business of teaching chemistry. In consequence, effective particle concepts, which ideally are developed over time, are introduced too quickly. This practice is likely to produce little understanding. Nonetheless, students' explanations in all their inconsistencies and diversity do provide excellent material to the teacher as potential conceptual resources, to be discussed, investigated and used as activities to provoke active thinking on the students' part. Multiple conceptual changes may be needed to help students develop a scientific understanding of particle theory and this is likely to involve a mix of conceptual addition and revision (Tyson et al., 1997). Hopefully, the kind of research reported here would catalyse action along those lines of conceptual change.

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