Teaching chemistry in primary science: What does the research suggest?

By Keith Skamp

The new Australian national science curriculum includes chemistry content at the primary level. Chemistry for young students is learning about changes in material stuff (matter) and, by implication, of what stuff is made. Pedagogy in this area needs to be guided by research if stepping stones to later learning of chemical ideas are to facilitate conceptual progress rather than hinder it. Further, recent findings advocate both the informal and formal introduction of aspects of the particulate model of matter at the primary level, provided certain teaching and learning strategies are used.

Chemistry in the National Primary Science Curriculum

The *Australian Curriculum: Science* (ACARA, 2011) outlines the 'science understandings' that primary (F-6) students are to encounter in the chemical sciences. In Foundation (F) to Year 2, the focus is awareness of self and the local world, while in Years 3-6 it is on what can be investigated scientifically. Chemical content descriptions and exemplar 'elaboration' examples for F-6 are in Figure 1 and are compared with a suggested progression based on recent research. Further examples of F-6 chemical activities linked to these ACARA understandings, are in ASTA's National Science Week resource book (Bucat et al., 2011).

As 2011 was the International Year of Chemistry, it is appropriate to ask how can primary teachers assist students in their conceptual understanding of these chemical ideas. The curriculum refers to 'objects', 'materials' and 'substances', as well as 'solids', 'liquids' and 'gases', and 'reversible' and 'irreversible change'. What do primary students intuitively think about these concepts and processes? How does their thinking develop? In what ways can teachers effectively assist concept formation related to these chemical ideas? Irrespective of the intentions a teacher may have when they engage young learners in activities connected with these concepts and understandings, their learners will inevitably ask questions and make comments such as 'what has happened and why?', 'where has it gone?', 'what is it now?', 'I think that it is...' and so on. What are teachers to say and do in such situations?

In the following, the most recent teaching and learning research connected to primary students learning chemical ideas is overviewed. Suggestions for more effective pedagogy are identified. Further, with an increasing focus on students learning through generating and testing their own representations of phenomena, more research is now indicating that this pedagogical approach can assist primary students in the stepwise development of a particulate understanding of matter. This is important, as the evidence points to certain teaching strategies enhancing later learning about this major conceptual scheme underpinning chemistry.

Objects, Materials and Substances

Each of these concepts is in the curriculum. Children are asked to think about what makes up materials such as plastics and glass. Initially it would be helpful if teachers were aware of their students'

YEAR OR RANGE	CONTENT DESCRIPTION	ELABORATION EXAMPLE	RESEARCH RECOMMENDATION
F-2	Different materials can be combined, including by mixing, for a particular purpose.	How paper may be changed and remade	Informal learning about matter
3	A change of state between solid and liquid can be caused by adding or removing heat.	Predicting the effect of heat on different materials	Properties and change involving water and air
4	Natural and processed materials have a range of physical properties; these properties can influence their use.	Investigating a particular property across a range of materials	
5	Solids, liquids and gases have different observable properties and behave in different ways.	Recognizing that substances exist in different states depending on the temperature	Conservation of matter and physical properties and change.
6	Changes to materials can be reversible, such as melting, freezing, evaporating; or irreversible, such as burning and rusting	Investigating irreversible changes such as rusting, burning and cooking.	Perceiving chemical properties and change

Figure 1: Chemical content in the Australian curriculum: Science (F-6) (ACARA, 2011) compared with a research recommendation (Lui & Lesniak, 2006).

existing conceptions about these ideas: see Figure 2; differences also will be discerned in the following discussion. Young learners can usually distinguish between objects and the materials from which they are made, and with guidance, usually the properties and uses of each. Some materials, such as metals, are more readily understood than others. Many students appreciate that properties of materials could be determined through scientific investigation, which is a curriculum focus for Years 3-6. Students though, usually have difficulty appreciating the origins of different materials (Krnel, Watson & Glazar, 1998; Russell, Longden, & McGuigan, 1991). There are exceptions to these generalisations such as students not realising that some materials and substances, which can occur in a range of forms, are not the same; an example would be iron powder and pieces of iron (Wiser & Smith, 2008). Numerous elicitation strategies, such as concept cartoons, can be used to discern student thinking about these aspects (e.g., see Skamp, 2012).

Object	An object is made of material(s)
Material	A material is made of substance(s)
Substance	A substance is composed of (contains) one or more element(s) (in combination)

Figure 2: Definitions of object, material and substance.

Classification of objects, materials and substances

Classification tasks are often associated with the exploration of the properties of objects and materials. Teachers need to ask what are the 'conceptual' strengths and limitations of any classification scheme they or their students introduce (e.g., 'made' materials compared to 'natural'). It needs to be stressed that classification schemes are human constructions used for particular purposes: an example would be to illustrate the connections between types of materials and their uses. A novel scheme related to materials and their properties suitable for upper primary is in Ross (1997).

A particular classification of materials and substances is whether they are solids, liquids or gases. Such a task would be a common occurrence at some stage in primary classrooms. Children would need to think about the properties of solids, liquids and gases and how they change state. In general, primary students can classify whether materials (and specific substances such as water) are liquids, although there can be a tendency to base their understanding on prototypes, such as water. Solids can create some difficulties, partly due to language usage; for example 'solid' is usually associated with hardness. As some solids can be 'soft', then this confuses many students. Gases are not well understood. Some students may think of them as dangerous and combustible and hence, for example, not see air as a gas; others may think of air as a prototype for all gases. Very young learners may struggle to talk about the nature of gases, while some older students will recognise oxygen and carbon dioxide as gases but on questioning, not be able to expand on their ideas (Krnel, Watson & Glazar [1998] and Wiser & Smith [2008] review research underpinning these findings).

Substances: A stumbling block for students

Primary students do not, in general, appreciate the difference between materials and substances. Substances are ('pure') chemicals comprised of one or more elements (see Figure 2); students may think of pure substances as 'natural' while 'processed' stuff is not 'pure'; they do not have a chemical sense of substance (see Note 1). The nature of substances is difficult for primary students because it relies on ideas such as specific melting and boiling points and it is abstract, in the sense that substances are made of unique particles which students are unable to see. Johnson's (2000) research led him to argue that the concept of substance must be explicitly 'taught'. This has direct implications for teachers as the curriculum (Years 3-6) refers to the mixing of substances and chemical change. As an aside, these ideas relate to the almost unbelievable discovery that materials are made of only 92 stable substances (elements) that comprise the periodic table. Although not usually introduced at the primary level, some teachers have engaged their students with this categorisation of elements (see, e.g., Skamp, 1993).

Is there a conceptual progression of ideas about objects, materials and substances?

Do these findings suggest a pattern of development in the formation of the concepts of object, material and substance? Unfortunately not! The overall 'developmental picture' is complicated and contested. There are, though, some general guidelines that can be 'trialled' by teachers. As might be expected, young children do initially learn about matter by acting on objects and materials (e.g., holding, blowing, pouring), and these actions may lead to the development of prototypes (e.g., water for liquids). The interaction of ideas about prototypes with properties of other substances (e.g., such as alcohol in the readily available material, methylated spirits) eventually may lead to the notion of 'substances', while the interaction of various actions with prototypes may lead to an appreciation of some physical and chemical processes, such as evaporation (Krnel, Glazar & Watson, 1998). The implications are at least two-fold: ensure that students have first hand experiences of objects, materials and selected substances but also that explicit scaffolding be associated with these hands-on experiences whereby teachers have their students openly discuss their conceptions of prototypes and compare and contrast them with other materials and substances.

Research-related recommendations for content and experiences at particular primary levels have been proposed (Figure 1) but Lui and Lesniak (2006, p.341) stress that there is 'no universal progression of ideas about matter'. In fact, each type of physical and chemical process (e.g., dissolving or burning) appears to have its own unique learning progression and even these 'progressions' may be different depending upon the material or substance that is the focus; further these 'progressions' are not necessarily age dependent.

Ways toward more scientific conceptual formation

Apart from the implied teaching suggestions above, the following may also assist in the development of concepts associated with objects, materials and substances. Teachers could:

- Encourage students to (a) empirically test their ideas, (b) develop more specific definitions for particular words, and (c) generalise from one specific context to another through discussion;
- Make imperceptible changes perceptible (e.g., use a microscope);
- Contrast the 'testing' of students' ideas with scientific ideas;
- Use secondary sources (For details see the SPACE project: see Harlen [2007] and Note 2.)
- Have students think through, and write about, their reasoning and then discuss with others (Levinson, 2000); and
- Use 2-D and 3-D concept maps (Howitt, 2009).

PARTICLES AND THE PARTICULATE MODEL OF MATTER

Primary students often use words such as atoms and molecules (Jakab, 2011). Should primary teachers encourage thinking about these 'particles' that comprise matter? When thinking about this issue, it is helpful to appreciate that matter can be conceptualised on three levels: macroscopic, microscopic and symbolic (see Figure 3). 'Microscopic' can be thought of as the 'particulate' level. The nature and properties of particles that comprise matter are encapsulated in the Particulate Model of Matter (see Figure 4). This model can explain how matter behaves and it is important as it underpins many chemical concepts in the curriculum. If teachers understand this model, it will influence their conversations with students about the nature and interactions of materials (and, where appropriate, substances). This is not to imply that you would 'tell' students the details of this model; rather, because you are aware of it, then the way you scaffold the content of conversations with your learners could enhance their later learning of chemical ideas; this will be exemplified in later examples.

Macroscopic	The perceptual or observable level
Microscopic	The particulate level
Symbolic	The representation of substances by symbols and the relationship between chemical symbols and the microscopic and macroscopic world.

Figure 3: Levels of conceptualisation of substances (Gabel & Bunce, 1994).

Particles display various properties in this model of matter. Some of these are:

- The conservation of particles: the same number before and after a physical change
- Their proximity: closer for solids, spread out for gases but always with space between them
- Their orderliness: ordered for solids, disordered for gases
- Their location (in a container): solids/liquids at bottom; gases spread out
- Their constancy of size and shape irrespective of phase changes
- Their discreteness
- Their chemical composition: the same for a physical change and different for a chemical change
- Their bonding is appropriate for particular molecules

Figure 4: The particulate model of matter (Adapted from Gabel, Samuel & Hunn, 1987).

Students' views about particles and matter

Most primary students intuitively think of liquids and gases as composed of 'continuous' stuff (or matter), but a few do think of stuff (especially solids) as comprised of particles. For these students, the properties of these particles often have 'macro' characteristics, for example, if the stuff was green then the particles in the stuff would be green; rarely would there be students who view the particles in matter having any of the properties as in Figure 4. Students will sometimes think about matter using all three 'frameworks' and then in an inconsistent way. What is interesting is that when students hold a continuous view of matter, it can impede later learning about the nature of matter. This also occurs for students who develop a 'molecules-in-matter' model, which is an amalgam of a continuous and a particle perception of what makes up stuff. This 'molecules-in-matter' model can be, inadvertently, 'supported' by teacher talk (e.g., 'atoms *in* solids vibrate...') and textbook figures and language (e.g., showing particles inside a square or cube). It is not surprising that students use these inappropriate representations. To do otherwise would mean they appreciate the non-intuitive idea that the particles in matter have *different* properties (as in Figure 4) to the realities they are dealing with, namely solids, liquids, gases and their changes and interactions (mixing, dissolving etc.)- see the 'green' example above. This is a large epistemological leap (!)- it is expecting students to think in a completely different way to what their senses indicate (Hatzinikita, Koulaidis, & Hatzinikita, 2005 and Wiser & Smith, 2008 further develop these ideas.)

Can primary students understand particulate thinking?

Until recently, it was accepted that the particulate nature of matter not be explicitly taught, or even introduced, at the primary level. An exclusive emphasis on the macroscopic behaviour of materials and substances was considered more appropriate. Over the years, this view has been questioned. Various intervention studies have described teaching where particulate ideas have been introduced and the impact this has had on primary students. There have been lesson sequences focussing on:

a. The formal introduction of particulate ideas, for example, to explain physical changes, and placing emphasis on alternative conceptions students may have, such as ascribing macroscopic properties to microscopic particles (several earlier studies had this focus, e.g., Lee et al. 1993);
b. Students learning about the three dimensional structure of simple molecules (e.g., ball and stick models) such as water and carbon dioxide, usually making some reference to bonding (e.g., Brown, Riston & Bencomo, 2008; Leisten, 2008); and
c. Students generating their own representations of matter, that is, mental models, and what is happening in their models when materials undergo change. Sometimes these models are then tested and refined (e.g., Tytler, Peterson, & Prain, 2006; Wiser & Smith, 2008).

In most instances, these studies have been with upper primary students. Several strategies were integrated into these approaches, such as aligning the particulate ideas with hands-on tasks, role-play and more recently computer simulations (for the latter see Papageorgiou, Johnson & Fotiades, 2008).

Although positive affective responses have been reported for (b) type sequences, there is little research data to support any long-term conceptual understandings deriving from the use of molecular models or an ability to transfer teacher-introduced particulate ideas to new contexts. Where strategies such as role-playing change of state (using some of the properties in Figure 4) have been used, the impact may have been beneficial (Skamp, 1999, 2008). These sequences did not have representational learning as a focus (as in [c]).

Sequences as in (a) were often quite lengthy with specialist guides for teachers (e.g., Lee et al., 1993). The focus was on modifying alternative conceptions that students held about particles. Interviews and paper and pencil feedback were usually the means of determining effectiveness. Some studies found certain phenomena were more readily 'understood' (at least partially) using particulate ideas, compared to other phenomena; for example, evaporation compared to decomposition. More success was reported when using a two-level approach, that is, a concurrent focus on the macroscopic event and the microscopic explanation. An example would be studying evaporation using hands-on (macroscopic) activities, with related and follow-up discussion which used diagrams and role-play to 'explain' the particulate nature of evaporation. In these studies, it was rare for students to generalise particulate explanations from one context to another and follow up studies showed many students had reverted back to non-particulate explanations (Skamp, 2008).

Sequences as in (c) have made student representations of ideas the focus of learning. These interventions acknowledge that students do have ideas about the nature of matter, albeit non-scientific ideas such as a continuous model, and teachers seek to 'work with' these student ideas. In this recent research, teachers have used the results of detailed findings of students' mental models of matter (e.g., Johnson, 2000, 2002). This has assisted teachers to use scaffolding of student tasks that shows promise of leading to more effective later learning about particulate ideas. This approach has even been beneficial in the lower primary years (Acher, Arca, & Sanmarti, 2007). The argument is that if appropriate 'intermediate' particulate models (not those outlined earlier such as 'molecules-in-matter') are developed as 'stepping stones', then students will more readily 'take on board' scientific particulate thinking at a later stage. The more appropriate pathway encourages students to hold models of matter that envisage separate particles, even if they are spoken about with (non-scientific) macroscopic properties; students who articulate such models were, for example, more able to visualise forces or bonds between the particles and relate such ideas to changes of state (Wiser & Smith, 2008). It is worth noting students do not appear "hindered in any way by their exposure to (some) particulate ideas", such as particles have "an ability to hold on to each other" (Papageorgiou & Johnson, 2005, p.1314, parentheses added).

A particulate sequence based on student-generated representations.

Wiser and Smith (2008) describe a lesson sequence that focussed on student generated representations and encapsulated the above research findings on moving towards scientific particulate thinking. Students were initially asked to generate their own notions (mental models) of what particular materials were made of, but the teacher said they had to imagine the materials being made of discrete entities. These models were then, through scaffolded discussion, narrowed down to various 'parts' models that had some similarities to the scientific particulate model; the 'parts' did not take on any nomenclature such as particles or molecules. The teacher then had the students manipulate their material (examples included 'breaking' clay, water, or wood) and simultaneously with this physical manipulation, they had to manipulate their mental models. The children had to imagine their materials having (1) as stated above, discrete parts; (2) a very large number of parts; (3) 'bonds' between the parts; and (4) the same number of parts before and after the changes. The teacher did this through, for example, encouraging reflection through imagination (e.g., 'How are the bits joined together?') and asked students to imagine 'bonds they cannot see' (for examples of the students' mental models, see Acher, Arca and Sanmarti [2007]). Teachers could apply similar ideas to these with their own students.

Hands-on and other 'chemical' tasks need related classroom conversations

These suggestions for moving students towards 'particulate model thinking' emphasise thoughtful teacher scaffolding and carefully listening to students' ideas and responding in particular ways. A classroom in which there is collaborative and conversational dialogue between peers, and between teacher and students so that children are at ease with discussing their ideas, is needed. 'Text' has been found to catalyse such dialogue, where text refers to the 'recounting of events, references to hands-on experiences and connections to prior discourse' (Varelas, Pappas & Rife, 2006, p.638). These authors reported how a Year 2 class engaged in extended collaborative and conversational dialogue over several lessons about condensation, evaporation and boiling. Interestingly, students initiated conversations about the recount of generalised events [GE] (e.g., fog), while teachers initiated most conversation about hands-on experiences [HOE] and prior classroom talk [PT]. HOE, followed by GE, led to the most science-oriented dialogue. This stresses two key issues. Firstly, I am not suggesting in this paper that HOE take a 'back seat'; rather I am arguing that the research urges teachers to engage in more open-ended discussion with students about their thinking (here related to the nature of matter). This discussion and thinking will often be associated with first-hand experiences and is similar to Hackling, Smith and Murcia's (2011) 'interactive-dialogic' communication. Secondly, students bring to their classroom science discussion, many ideas from their prior experiences that they want to talk about.

Apart from Wiser and Smith's (2008) lesson sequence example above, Hatzinikita, Koulaidis and Hatzinikita (2005) provide another which illustrates how teachers can subtly redirect students' open-ended conversation towards particulate thinking. Teachers often focus children's thinking only on perceptual aspects of materials (e.g., colour, physical state), which can tend to inadvertently reinforce students' intuitive ideas about matter being continuous. If teachers, however, noticed when children made comments about, say, the 'arrangement' or 'location' of particles or pieces of materials or substances, during conversation about dissolving, then they could redirect the focus of discussion to these aspects which may commence movement towards a more scientific particulate view. What is suggested here is not 'interactive-authoritative' discussions (again see Hackling et al., 2011), but simply a gentle nudge in that direction - this is because the development of particulate thinking takes time.

Integrating research findings with curriculum resources

The widely known Australian primary science curriculum initiative Primary Connections, has developed units titled 'What is it made of?', 'Material world' and 'Package it better' (Australian Academy of Science [AAS], 2008a, b, c). Teachers using these units could integrate into their teaching the outlined research findings about students' development of the concepts of object, material and substance, as well as particulate ideas.

Changes in Materials and Substances

Physical and chemical changes are in the curriculum (see Figure 1) and in common curriculum resources, such as the Primary Connections units (e.g., see above and 'Change detectives' [AAS, 2009a] and 'Spot the difference' [AAS, 2009b]). Research indicates that learning about reversible physical changes such as dissolving, melting, freezing, evaporation and condensation should precede irreversible chemical changes such as burning (Wiser & Smith, 2008).

Physical changes: students' ideas

Summaries of primary students' ideas and their development about different physical changes are available (e.g., see Skamp, 2012). Space limitations mean they cannot be described here. This research, in broad terms, indicates that often primary students:

- Confuse melting and dissolving and do not conserve mass during melting and freezing changes;
- Tend to understand evaporation more readily than condensation. With evaporation, liquid going into the 'local' air rather than 'water cycle' notions of

where the liquid had gone, are slow to develop. With condensation, students find it hard to believe that there is always water vapour in the air and hence suggest the condensed water has come from elsewhere; and

- Believe there is an increase in mass with expansion due to heating (e.g., of metals). This could be due to thinking heat is a substance.

Each of these generalisations suggests tasks (e.g., have students weigh materials before and after a phase change; use a liquid different to water such as eucalyptus oil for evaporation) and probes that teachers can use to progress conceptual thinking.

Progression of ideas about physical change

There is not consensus as to whether students develop ideas about physical change following particular trajectories that have been suggested in the literature. These 'trajectories' (e.g., for evaporation from ages 5 to 13, the water disappears; it is absorbed by solid objects; it 'evaporates' into some container; it evaporates into the sky; it goes into the air and changes phase) do have 'guidance value' but each child follows their own conceptual pathway. These individual pathways are influenced by many factors such as the context in which the learning is occurring, what each child perceives to be the purpose of the activities undertaken, each child's perceived classroom identity (e.g., do they see themselves as 'explorers of ideas') and even such abstract notions as how children conceive reality, such as, is 'coldness' a substance or a property. Clearly, teachers need to listen carefully to what students are saying about hands-on or remembered physical change experiences, and then (a) engage them in conversations that are cognisant of the difficulties students may have with particular types of physical change and (b) appreciate that each child will be following their own specific, and usually, non-linear trajectory towards understanding what is happening.

Physical changes: Ways toward more scientific conceptual formation

A summary of advice from the research literature on physical change (especially change of state) would include, for each type of change, teachers:

- Using a wide variety of contexts and talking about them all together in classroom discussion;
- Including familiar anecdotes of everyday occurrences of the change;
- Referring to examples other than ice and water;
- Encouraging students to represent their observations and understandings in various forms; examples would be descriptive (verbal, graphic, tabular), experimental, mathematical, figurative (pictorial, analogous, metaphoric) and kinaesthetic. Students need to discuss the links between their various representative forms, as well as the limitations of each representation;
- Appreciating whether a pre-requisite concept may need to be considered, such as all air contains water;
- Avoiding language that might suggest that changes of state result in different materials or substances;
- If appropriate, using objective, rather than simply perceptual, measures (e.g., weighing rather than simply observing);
- Highlighting similarities and not just differences; and
- Not simply 'telling' students an accepted scientific view; rather use some of the above, or other alternatives, as a means of a way forward.

(Derived from Driver et al. 1994a; Johnson 1998, 2002; Ross and Law 2003, Tytler 2000; Tytler and Peterson 2000; Tytler, Peterson and Prain 2006; Tytler, Prain and Peterson 2007; Tytler and Prain 2010; Wiser and Smith 2008)

Physical changes: Value of a particulate perspective

The above advice need not necessarily involve students in particulate thinking. However, it is worth noting that when students cannot distinguish between the properties of macroscopic entities (e.g., a liquid) and the particles that comprise them, then this will lead to real difficulties in advancing their thinking about physical change. Introducing students to the idea of particles and 'bonds' between them, as described earlier, will provide them with alternative explanations for physical changes to those they intuitively hold and hence advance understanding (Wiser & Smith , 2008). Descriptions of the impact of evaporation and condensation lesson sequences for upper primary revolving around explanations based on student-generated representations of particles and their movement, which are then tested and refined, support this conclusion (Kenyon, Schwarz and Hug, 2008; Tytler, Peterson, & Prain, 2006).

Overall, there is mounting evidence that students benefit from being introduced to aspects of the particulate model when investigating physical changes. This is the case if non-traditional pedagogy, with a focus on student representations, is used. These representations can take many forms and be multimodal (see earlier and next).

Physical change: Teaching towards a particulate model

A review of physical change studies that have introduced particulate ideas to primary students would suggest, among a wider range of advice, that teachers:

- Use multiple modes of representation and those that are accessible to the students (e.g., use of arms, legs, drawings, words);
- Integrate scaffolded role-play and related tasks associated with macroscopic/concrete observations. Try to ensure the role play is consistent with accepted scientific views;
- Not feel that 'complete' particulate explanations need be introduced, even though thinking has moved in that direction;
- Negotiate meanings of student representations as if it were a two-way process;
- Introduce the idea of levels of 'ability to hold' between different particles;
- Explicitly indicate that using representations are ways that we (and science) try to understand phenomena and that it is an ongoing process; and
- Use, if available, carefully scaffolded multi-media depicting particulate motion, realising additional benefits may mainly be affective.

(Based on Jackson, 2009; Papageorgiou, G., Johnson, P. & Fotiades (2008); Tytler and his colleagues' various publications).

Overall, teachers need to be aware that, firstly, using student generated representations in the above ways is different to how many teachers would use representations (i.e., in order to 'instruct' or 'explain'), and hence their students may find learning in this way to be unusual. Secondly, developing an understanding of the particulate model can take many years; the pathway could include many stepping stone ideas.

CHEMICAL CHANGE

Chemical change (see Figure 5) is far more difficult for primary students. They usually do not distinguish between it and physical change. Learning is further inhibited because they have a non-chemical view of 'substance' and usually a non-particulate view of matter- both are fundamental to explaining chemical change. Further, many chemical changes involve gases (e.g., oxygen and carbon dioxide) which are the least well understood state of matter. As with physical changes, there have been problematic research-based descriptions for how students develop the concept of chemical change. One progression is from 'it's just like that', to displacement, then modification, followed by transmutation of matter, and then the scientific idea of chemical interaction (for an elaboration of this and other progressions, see Skamp, 2012). As with physical changes, these can be a broad guide, but each student will follow their own conceptual trajectory, which may zig-zag and bear little resemblance to literature progressions.

A chemical change is one in which:

- The amounts of reactants decrease over time.
- New substances are formed and the amounts of these increase over time – although that time might be very short indeed.
- The total mass of new substances that have been formed at any time is the same as the total mass of reactants that have been 'consumed'; this is usually called the 'conservation of mass'.
- The number of atoms of each element in the new substances that have been formed at any time is the same as the number of those atoms in the amounts of reactants that have been consumed; this is usually referred to as the 'conservation of atoms'.
- During reaction, chemical bonds between some atoms in the reactant molecules are broken and chemical bonds between other atoms are formed, creating new molecules (or products).
- Because chemical change involves the redistribution of atoms (or the making and breaking of bonds), molecules of the reactants are not conserved.
- The molar amounts of new substances that have been formed at any time are related, usually by simple ratios, to the molar amounts of reactants that have been consumed.

Figure 5: The nature of chemical change (Bucat & Fensham, 1995)

In fact, several classroom-based studies indicate that many middle school students still struggle with the chemical concept of 'substance' and that it will not be understood until some sense of the particulate model of matter is grasped (e.g., see Johnson, 2000). This implies that those partially scientific models of matter discussed earlier, where matter is comprised of 'spaced particles, and only of those particles, and in which they have macroscopic properties of a substance, including its state' (Wiser & Smith, 2008, p.230), can be stepping stones to a particulate model of matter. This will lay the foundations for understanding chemical change at a later stage. Even laying these foundations, chemical change will not be understood, in particulate terms, by the vast majority of primary students. As it is in the curriculum, through experiences such as cooking, burning, rust and other interactions of materials and substances (e.g., vinegar and baking soda), then how are teachers to encourage students to think about these everyday chemical changes?

Chemical change: Ways toward more scientific conceptual formation

Considering the above difficulties, teachers need to encourage students learning about chemical change to initially focus on macroscopic observable differences. Teachers can further assist conceptual development by adapting many of the suggestions outlined for physical change pedagogy as well as:

- Encouraging students to think about the products of the change as new materials (and substances), rather than products that are still directly related to the starting materials (e.g., try to avoid giving the impression that rust is still iron). Point out if invisible gases are produced. Use new names for the products of reactions (e.g., soot and even gaseous names, such as carbon dioxide). Simply applying these suggestions will not necessarily change students' ideas but it is using language carefully and may lay stepping stone ideas.
- Remembering that change in appearance does not mean that students believe that chemical change has occurred. Students may still think that the same materials (and substances) are there.
- Helping children to appreciate that materials (and substances) can be in contact with each other, and not change, and contrast these situations with when change does occur. Primary students often attribute change to one substance rather than the interactions between substances. Teachers, therefore, can encourage dialogue which focuses on the concept of 'interactions'.
- Considering whether analogies could assist, while remembering to discuss the strengths and limitations of analogies: for example, change a Lego truck into a person's face using the wheels for eyes- burning of wood to form ash and fumes could be compared to the truck no longer being there. This may even suggest to some students the conservation of matter during chemical change.
- Introducing, with older students, word equations which may emphasise that new substances are formed.
- Reiterating that stuff (matter) cannot just be created; students may not believe you but it may challenge some.
- Not feeling compelled to use everyday examples of chemical change; sometimes contrived contexts (e.g., blue copper sulphate and water) can be more instructive than complex familiar situations (e.g., cooking an egg).
- Moving conversation beyond observing and describing chemical change and opening up 'spaces' for students to venture with their 'explanations' in an atmosphere of negotiating and debating meanings and understandings. This would be consistent with children's meaning-making and representational learning about states of matter as described earlier.

The task for the teacher is to lay conceptual stepping-stones for later learning about chemical change rather than forcibly introduce ideas that may confuse, rather than clarify, such as the chemical rearrangement of atoms.

(Derived from from Driver et al. (1994), Griffin & Sharp (1998), Johnson (2000), Lui and Lesniak (2005), Papageorgiou & Johnson (2005), Rahayu and Tytler (1999), Ross and Law (2003), Valeras, Pappas and Rife (2006) and Valeras et al., (2008)).

SUMMARY: WHERE TO FROM HERE?

Chemistry is in the primary curriculum. Primary teachers initially should place emphasis on the first-hand experiences and macroscopic properties of matter (objects and materials, and at times, substances) and how it changes. Even when particulate ideas are not part of the classroom discussion, there are still many pedagogical suggestions that can be used that are not inconsistent with a scientific perspective.

The particulate model of matter is not an intuitive idea for most primary aged students. Primary students, though, are capable of fairly complex thinking, and we should not underestimate what children, even in lower primary, may be capable of learning about particulate ideas when teachers use non-traditional pedagogy (Varelas, Pappas & Rife, 2006). Recent research indicates that formally (or informally) introducing particulate ideas, through a focus on student generated representations and associated teacher scaffolding which orients discussion towards certain types of 'intermediate' particulate models, will assist later learning about this most powerful conceptual scheme. Further, you can be reassured that the formal introduction of some particulate ideas need not hinder primary students' conceptual development. When particulate thinking as an explanatory model becomes the focus, teachers need be cognisant of several nuances: some of these are remembering to appreciate students' existing (and intuitive) ideas, using multiple representational modes, and having extended conversational dialogue and meaning-making about the first hand experiences to which particulate ideas may be applied.

Notes

1. A substance by definition has a fixed identity because of its atomic structure and so it is actually inappropriate to say to refer to a 'pure' substance.
2. SPACE refers to the Science Process And Concept Exploration project which explored young children's understanding of science (see http://sci-tutors.gnxt.net/downloads/professional_issues/teaching/misconceptions/the_space_reports.pdf)

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