Enhancing students' use of multiple levels of representation to describe and explain chemical reactions

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A new instructional programme aims to achieve more meaningful learning of chemical reactions among 15–16 year-old students instead of mere rote learning

The prescribed chemistry curriculum for grade 9 students (15–16 year-olds) in Singapore secondary schools includes several types of chemical reactions. The students often memorise chemical equations, and the accompanying changes for the reactions, and regurgitate them in tests and examinations. We believed that students would understand chemical reactions better if they were able to explain the changes by making use of different *levels of representation*.

Three levels of representation often used in chemistry are:

- the **macroscopic** level, which describes the bulk properties of matter;
- the **submicroscopic (or molecular)** level, which provides explanations at the particulate level in which matter is described as being composed of atoms, molecules and ions;
- the **symbolic (or iconic)** level, which includes the use of chemical symbols, formulae and equations to symbolise matter (Johnstone, 1993; Nakhleh and Krajcik, 1994).

ABSTRACT
This article reports on the efficacy of an instructional programme designed to facilitate 15–16 year-old students' use of multiple levels of representation when describing and explaining chemical reactions. After nine months of instruction, the 65 students taught through this supplementary programme were found to have achieved better understanding of the use of multiple levels of representation than another group of grade 9 students who were not instructed using this programme.

Studies have shown that students generally construct most of their understanding in chemistry at the macroscopic level of representation but are not very successful in building understandings that relate the macroscopic representational level to the submicroscopic and symbolic representational levels (Nakhleh and Krajcik, 1994). This trend in students' construction of knowledge could be attributed to their prior knowledge of chemistry, which is entrenched mainly at the macroscopic level of representation as a result of their everyday experiences.

Purpose of study

This study was conducted in order to evaluate the efficacy of an instructional programme designed specifically to facilitate 15–16 year-old (grade 9) Singapore students' use of the macroscopic, submicroscopic and symbolic levels of representation when describing and explaining chemical reactions.

Methodology

Seven types of chemical reactions are included in two major topics in grade 9, namely, the properties of acids, bases and salts, and the metal reactivity series. These chemical reactions involve the burning of metals, action of dilute acids on reactive metals, metal oxides and carbonates, neutralisation of strong acids by strong alkalis, ionic precipitation, and metal ion displacement.

A supplementary programme of instruction designed to reinforce the use of multiple levels of representation when describing and explaining chemical reactions was designed and incorporated into the prescribed scheme of work. The main features of the supplementary teaching programme were:

- incorporating additional laboratory activities to familiarise students with chemical reactions;
- explaining the observed chemical changes at the particulate and symbolic levels (an example is illustrated in Figure 1 for a strong acid – strong alkali neutralisation reaction);
- emphasising the significance of coefficients and subscripts in chemical and ionic equations;
- deducing ionic equations from observed chemical changes (not by mechanically 'cancelling out' 'spectator ions' in chemical equations).

The programme of instruction was implemented by the first author over nine months with 65 students in two grade 9 classes. At the end of the instruction a two-tier multiple-choice diagnostic instrument consisting of 15 items, the RSCRDI (Representational Systems and Chemical Reactions Diagnostic Instrument) developed by the authors (Chandrasegaran, Treagust and Mocerino, 2005) was administered to the two classes as well as to two other higher achieving classes of students that had been instructed by another teacher using the normal prescribed instructional programme. An example of one of these items (item 14) is reproduced in Box 1.

Findings and discussion

Statistical analysis of students' responses to the 15 items revealed that the mean score of students involved in the supplementary instructional programme was significantly higher than that of the students who were instructed using the prescribed programme. The overall results for the two groups of students are summarised in Figure 2 in which a shift to higher scores among students in the former group is apparent. Scores in the range from 10 to 15 marks were obtained by 71% of students involved in the

BOX 1 Example of a two-tier multiple-choice item in the RSCRDI

Item 14

When powdered zinc is added to blue aqueous copper(II) sulfate and the mixture shaken, the blue colour of the solution gradually fades and becomes colourless. At the same time a reddish-brown deposit is produced.

The chemical equation for the reaction that occurs is:

$Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$,

while the ionic equation is:

$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$.

Why did the solution finally become colourless?

A Copper has formed a precipitate.

B Zinc is more reactive than copper(II) sulfate.

C The copper(II) sulfate has completely reacted.

D Zinc has dissolved, just like sugar dissolves in water.

The reason for my answer is:

1 Zinc ions are soluble in water.

2 Zinc loses electrons more readily than copper.

3 Soluble, blue Cu^{2+} ions have formed insoluble, reddish-brown copper atoms.

4 In aqueous solution Cu^{2+} ions produce a blue solution, while Zn^{2+} ions produce a colourless solution.

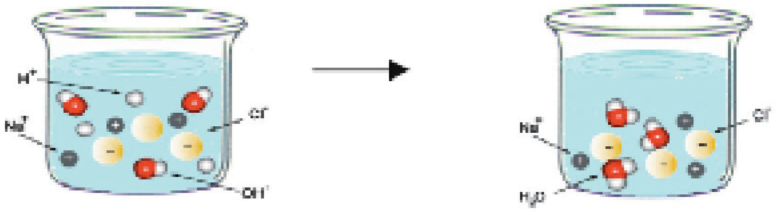

Figure 1 Particles before and after a strong acid – strong alkali neutralisation reaction. (Adapted from British Columbia Institute of Technology website: http://www.bcit.ca)

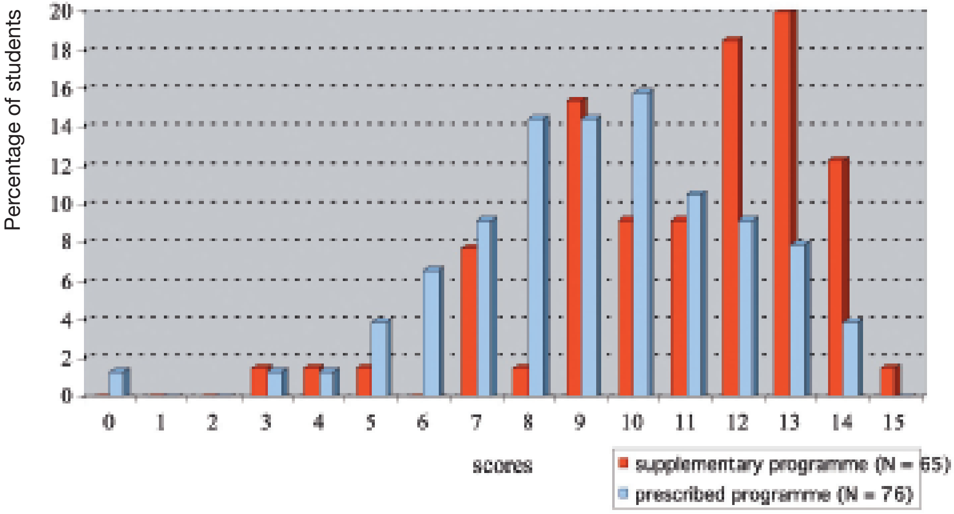

Figure 2 Distribution of RSCRDI scores.

supplementary instructional prgramme but by only 47% of students who were involved in the prescribed programme.

Despite efforts to emphasise the changes in chemical reactions using multiple levels of representation during instruction, several inappropriate conceptions were found to persist among the students involved in the supplementary instructional programme. This finding is not unexpected as students' conceptions are known to be deeply rooted and resistant to change (Treagust and Chittleborough, 2001). Several of these student conceptions, deduced from their responses, are discussed below.

First, there were instances when students displayed confusion between the macroscopic level of representation and the submicroscopic one (Andersson, 1986). When, for example, aqueous sodium hydroxide reacts with dilute nitric acid, the overall change is the formation of aqueous sodium nitrate and water (macroscopic level). At the submicroscopic level, the change involves the removal of H^+ and OH^- ions to produce water molecules. Twenty per cent of students, however, indicated that at the submicroscopic level Na^+ and NO_3^- ions had reacted to produce aqueous sodium nitrate (macroscopic level). Also, in the chemical reaction between iron powder and dilute hydrochloric acid, a green aqueous solution is produced (macroscopic level). This colour change from colourless to green may be attributed to the presence of Fe^{2+} ions in solution (submicroscopic level). Fifteen per cent of students, on the other hand, suggested that atoms of iron and chlorine had changed colour as a result of the reaction, indicating confusion between the colour change of the aqueous solution at the macroscopic level and the changes involving the elements iron and chlorine at the submicroscopic level.

Second, the tendency to extrapolate the bulk macroscopic properties of substances to the particulate level (Andersson, 1986; Ben-Zvi, Eylon and Silberstein, 1986) was particularly evident among 31 per cent of students who attributed the blue colour of aqueous copper(II) sulfate to the *blue colour of individual* Cu^{2+} *ions*. (What would these students have to say about the colour of Cu^{2+} ions in white anhydrous copper(II) sulfate and black copper(II) oxide?) According to the kinetic theory, the particles in matter possess the mechanical properties of mass and motion. As colour is not a mechanical property it cannot, therefore, be inferred that the Cu^{2+} ions possess the blue colour of the bulk substance of which these ions are part (Albanese and Vicentini, 1997). It may be more appropriate to state that *the blue colour of aqueous copper(II) sulfate is caused by the presence of* Cu^{2+} *ions in solution*. The same students (31 per cent) attributed the decrease in intensity of the blue colour of the solution and the formation of a reddish-brown deposit in the chemical reaction between zinc powder and aqueous copper(II) sulfate to the removal of *blue* Cu^{2+} *ions* from aqueous solution to produce *reddish-brown, insoluble atoms of copper*.

Conclusion and implications for classroom practice

The findings of this study suggest two main implications for classroom practice. First, classroom instruction may be organised in a manner that takes into account students' conceptions similar to those identified in the study. When students are directly confronted with conceptions that they realise are not scientifically acceptable and through small-group discussions with the teacher and peers, students may be led to arrive at more fruitful understandings of the changes during chemical reactions.

Second, by making use of the strategies incorporated in the instructional programme that was implemented in this study teachers could help further consolidate students' understandings of the use of multiple levels of representation.

In conclusion, the findings of this study recognise the need for a change in the Singapore chemistry curriculum in order to engender more meaningful learning about chemical reactions instead of mere rote learning of chemical equations.

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