PRE-SERVICE TEACHERS' CONTENT WEAKNESSES CONCERNING CHEMICAL BONDS AND BONDING

Boo Hong Kwen
Email address: hkboo@nie.edu.sg

INTRODUCTION

Research has demonstrated that many university students complete degree courses without a good grasp of the subject which they have majored in (Birk & Kurtz, 1999; Bodner, 1991; Dart et al., 1998). Studies on content knowledge of pre-service teachers have revealed that these teachers lack understanding of fundamental science concepts that they are supposed to teach after their training (Gabel, Samuel & Hunn, 1987; Preece, 1997; Trumper & Gorsky, 1997). Weaknesses in content knowledge howerever are not limited to pre-service teachers. Research has also revealed that practising or in-service teachers hold misconceptions about topics which they are involved in teaching to their students (Banerjee, 1991; Berg & Brouwer, 1991; Kruger, Palacio & Summers, 1990; Kruger & Summers, 1989; Parker & Heywood, 1998; Preece, 1997). Some researchers have taken the research further by exploring the sources of these content weaknesses or misconceptions and have implicated textbooks or instructor comments as possible sources (Garnett, & Treagust, 1992; Sanger & Greenbowe, 1997, 1999).

BACKGROUND

For several years now, I have been teaching a module on assessment in chemistry each year to a group of science graduates who have studied chemistry up to university level. Based on my interaction with these students, I have built up a list of some of the common content weaknesses or misconceptions held by these students. In this article, I would like to share from this list, and to confine myself to the topic of chemical bonds and bonding. I also include along with each content weakness or misconception my views on what I consider to be a more acceptable view. Where appropriate, I discuss possible reasons for students' misconceptions or weaknesses in the specific content.

CONTENT WEAKNESSES OF PRE-SERVICE TEACHERS

1. *There is no difference between the terms "chemical bonding" and "chemical bond". More specifically, the term "ionic bonding" is synonymous with "ionic bond" and "covalent bond" is synonymous with "covalent bonding".*

The subtle difference between the terms "bonding" and "bond" needs to be pointed out. The term "bonding" refers to the process of bond formation whereas the term "bond" refers to the attractive force which holds ions or atoms or molecules together. For example, we would say that the term "covalent bonding" refers to "the sharing of electrons between atoms of non-metallic elements, generally resulting in a noble gas structure in the valence shell of the atoms involved". Whereas the term "covalent bond" refers to " the attraction between the positively charged nuclei (of the two atoms comprising the molecule) and the pair of shared electrons".

2. *An ionic bond is electrostatic in nature but not the covalent bond.*

This is a misconception because all chemical bonds (including metallic bonds, Van der Waals bonds and hydrogen bonds) are electrostatic in nature.
The misconception may have risen because textbooks tend to mention that "ionic bond is the electrostatic attraction between positively charged and negatively charged ions" whereas generally there is no parallel mention of the nature of the covalent bond. Because there is no mention that the

covalent bond is electrostatic in nature, many students infer for themselves that the covalent bond is not electrostatic in nature.

In fact many textbooks not only fail to point out that covalent bonds are electrostatic in nature, but also state explicitly that "a covalent bond is the pair of shared electrons in a covalent molecule" thus perpetuating the following misconception no.3.

3. *A covalent bond is the pair of shared electrons in a covalent molecule.*

This is a content weakness or inaccuracy because a chemical bond must be a force, an attractive force, and a pair of electrons by themselves cannot constitute an attractive force. A more accurate statement would be: " A covalent bond is the attraction between the positively charged nuclei (of two atoms comprising the molecule) and the pair of shared electrons. "

4. *An ionic bond could be formed with small numbers of atoms or molecules. For example, two atoms of sodium metal and a molecule of chlorine will form two ionic bonds, each between a positively charged sodium ion and a negatively charged chloride ion.*

This is a misconception because the energy required for ionising the sodium atoms (ionisation potential of sodium) as well as the energy required for breaking the covalent bond in the diatomic chlorine molecule (bond dissociation energy of chlorine) cannot be compensated by the electron released when the two chlorine atoms each gain an electron from the sodium atoms (electron affinity of chlorine). Instead it must be compensated by the crystal lattice energy, which is the energy released in the formation of a crystal lattice. Small numbers of ions are therefore insufficient for the formation of such a crystal lattice which must be made up of huge numbers of ions.

The correct scientific view is that in order for bonding to occur, huge numbers of particles in the order of Avogadro's number ($6.023X10^{23}$) must be involved, i.e. certain numbers of moles of particles must be involved.

One of the possible reasons for the misconception could probably be traced to many textbooks' treatment of the topic "ionic bonding" which involves illustration with **small numbers** of atoms or molecules, and which contains no mention of the formation of the crystal lattice.

This misconception is further reinforced by the existence of multiple choice questions such as the following which can be found in assessment books or school tests:

How does a magnesium atom form a bond with an oxygen atom?
A. By sharing one pair of electrons, both electrons provided by the magnesium atom.
B. By sharing two pairs of electrons, each atom donating one pair of electrons.
C. By giving one pair of electrons to the oxygen atom.
D. By giving two pairs of electrons to the oxygen atom.

Which one of these statements about the formation of ionic bonds in the given compound is **not correct**?

A. $Mg^{2+}O^{2-}$	Four electrons are transferred.
B. $(Al^{3+})_2(O^{2-})_3$	Six electrons are transferred.
C. $Ca^{2+}Cl^{2-}$	Two electrons are transferred.
D. $Na^{+}Cl^{-}$	One electron is transferred.

In the above two multiple choice questions, in both cases only small numbers of particles are involved in the formation of ionic bonds.

5. *Covalent bonds are weaker than ionic bonds.*

This is a misconception because both ionic and covalent bonds are very strong bonds; and comparison of strengths cannot really be made between these bonds per se.

This misconception probably arises out of the general notion that covalent substances generally have lower melting points and boiling points compared to ionic substances, together with inadequate textbook treatment on the concepts of bonding.

In many textbooks the discussion on bonding often does not include the explanation that ionic bonding results in the formation of a giant ionic crystal lattice structure whereas covalent bonding usually results in the formation of simple or discrete molecular structures.

The notion that melting (or boiling) an ionic substance involves breaking the ionic bonds (which are the attractive forces between the oppositely charged ions) while melting (or boiling) a covalent substance with simpler molecular structures does not involve breaking the strong intra-molecular bond (ie the covalent bond within the molecule) but only involves breaking the relatively weaker bonds between molecules (the intermolecular bonds such as Van der Waals' forces or hydrogen bonds) is often not pointed out.

6. *Water can break ionic bonds.*

This is a content weakness or inaccuracy because ionic bonds could only be broken by the absorption of energy (made available through the solvation of the ions by the water molecules) and not merely by the presence of water.

The source of this kind of weakness could perhaps be traced to inaccuracies in the language used by teachers or even textbooks. It should be noted that ionic bonds are forces, and forces can only be overcome by energy input and not by mere presence of water.

Evidence of this weakness can be found in some of the multiple choice questions in assessment books or school tests, an example of which is given as follows.

> Which one of the following statements about ionic bonds is **false**?
> A. They are electrostatic in nature.
> B. They are as strong as covalent bonds.
> C. They are not easily broken by water.
> D. They are formed between metallic and non-metallic atoms.

In the above multiple-choice question, the intended answer key is option 'C' which is not accurate from a scientific point of view as discussed above.

DISCUSSION AND IMPLICATIONS

The content weaknesses or misconceptions discussed reveal a concern regarding the formal science instruction that these pre-service teachers have received in their schooling days. It is likely that these may be traced to language or illustrations used by either textbooks or teachers. It could also be that some of the misconceptions are held by the teachers who are unaware of these as such, and are hence unknowingly, perpetuating these ideas.

These concerns highlight a need, on one hand, to address the language or illustrations or inaccuracies used in textbooks and other curricula material, and on the other hand, a need to address the misconceptions through pre-service as well as in-service teacher education.

In terms of pre-service education, one way is to provide curriculum time to address these content weaknesses and misconceptions during in-service training. However, it is questionable whether these content weaknesses can be fully addressed within the time constraints imposed upon current pre-service teacher education courses. A possible alternative is to address these through in-service courses, which could be school-based (as part of the 100 hour of in-service training targeted for practising teachers) and which could involve all science teachers taking responsibility for providing guidance and instruction on problematic topics to their peers.

With respect to sources of misconceptions or content weaknesses, there is a need for both curriculum developers and instructors to carefully select explanatory language, and illustrations as well as to exercise great caution in making unqualified or imprecise or careless statements because these can lead to student misconceptions or content weaknesses.

REFERENCES

Banerjee. A. (1991). Misconceptions of students and teachers in chemical equilibrium. *International Journal Science Education, 13*(4), 487-494.

Berg, T. & Brouwer, W. (1991). Teacher awareness of student alternate conceptions about rotational motion and gravity. *Journal of Research in Science Teaching, 28*:3-18.

Birk, J.P. & Kurtz, M.J. (1999). Effect of experience on retention and elimination of misconceptions about molecular structure and bonding. *Journal of Chemical Education, 76*(1), 124-128.

Bodner, G. (1991). I have found you an argument - The conceptual knowledge of beginning chemistry graduate students. *Journal of Chemical Education, 68*(5), 385-388.

Dart, B.C., Boulton Lewis, G.M., Brownlee, J.M. & McCrindle, A.R. (1998). Changes in knowledge of learning and teaching through journal writing. *Research Papers in Education, 13*:291-318.

Gabel, D., Samuel, K. & Hunn, D. (1987). Understanding the particulate nature of matter. *Journal of Chemical Education, 64*(8), 695-697.

Garnett, P. J. & Treagust, D. F. (1992). Conceptual difficulties experienced by senior high school students of electrochemistry: electric circuits and oxidation-reduction equations. *Journal of Research in Science Teaching, 29*(2), 121-142.

Kruger, C. & Summers, M. (1989). An investigation of some primary school teachers' understanding of changes in materials. *School Science Review, 71*: 17-27.

Kruger, C., Palacio, D. & Summers, M. (1990). An investigation of primary school teachers' conceptions of force and motion. *Educational Research, 32*: 83-95.

Parker, J. & Heywood, D. (1998). The earth and beyond: developing primary teachers' understanding of basic astronomical events. *International Journal of Higher Education, 20*: 503-520.

Preece, P.F.W. (1997). Force and motion: pre-service and practising secondary science teachers' language and understanding. *Research in Science and Technological Education, 15*(1): 123-128.

Sanger, M. J. & Greenbowe, T.J. (1997). Students' misconceptions in electrochemistry: current flow in electrolyte solutions and the salt bridge. *Journal of Chemical Education, 74*(7): 819-823.

Sanger, M. J. & Greenbowe, T.J. (1999). An analysis of college chemistry textbooks as sources of misconceptions and errors in electrochemistry. *Journal of Chemical Education, 76*(6): 853-860.

Trumper, R. & Gorsky, P. (1997). A survey of biology students' conceptions of force in pre-service training for high school teachers. *Research in Science and Technological Education, 15*(2), 133-147.

****

Dr Boo Hong Kwen is an associate professor of the Science and Technology Education Academic Group at the National Institute of Education, Nanyang Technological University.