MISCONCEPTIONS IN THE TEACHING OF CHEMISTRY IN SECONDARY SCHOOLS IN SINGAPORE & MALAYSIA

CHU CHIT KAY
HONG KOH YIIN
Department of Pre-University Programmes
Sunway College Johor Bahru

ABSTRACT

Misconceptions are erroneous perceptions of what is universally accepted as physical laws that have been experimentally tested to date. There are many sources of misconceptions in the teaching of Chemistry and the origins of some of these misconceptions are discussed with reference to Malaysian and Singapore students. Surveys on students in the form of questionnaires, and Chemistry teachers having to conduct microteaching sessions with peer evaluations, have been shown to be effective tools in identifying some misconceptions among students and teachers. Many of these misconceptions are common with students of Chemistry world-wide arising mainly from text books and our general perceptions of things through multi media. Surveys in the form of questionnaires and micro-teach have been conducted to identify both students' and teachers' perceptions. Some of these misconceptions identified are derived from peers, family members within our different ethnicity and cultures. This is particularly important in this region of the world where there is so much diversity in language and culture. Malaysia, for example, has used English as the medium of instruction, reverted to Bahasa Malaysia and back again to English in the teaching of Science. This will invariably bring about a shift of conceptual visualization as we change from one language to another. The surveys also highlighted the importance of peer evaluation in an attempt to make teachers more aware of their misconceptions.
The paper is by no means exhaustive and hopes to provide a general guideline for teachers of Chemistry in the region, to be aware of such misconceptions during their teaching of the subject.

Key words: Chemistry, education, misconceptions, Singapore and Malaysian schools.

INTRODUCTION

"An elephant is like a wall!" exclaimed the blind man feeling the body of an elephant. "No, No," cried another blind man pulling the tail. "An elephant is like a rope!" "You are all wrong, an elephant is like a fan!" said yet another stroking the ear of the elephant.

Such are the misconceptions of things that we cannot see. Our understanding of Chemistry is not very much different from the misconceptions of the blind men. We are not able to "see" atoms and electrons, hence, we have to conceptualise them using mathematical representations and models which are often erroneous. Inherently, we are subjected to these misconceptions. It has been observed that many students still find it difficult to comprehend emptiness between atoms and molecules (Griffiths, 1992; Novick & Nussbaum, 1978). There are students with chemistry knowledge which is conceptually wrong, yet doing very well in algorithmic questions. Mulford (1996), in his dissertation observed that students can attain high grades in Chemistry while still having a high level of misconceptions.

It is often difficult to identify misconceptions among students, largely because they all come from different backgrounds and have different levels of cognitive ability There are many attempts to assess students' misconceptions, and they are well-documented in the literature (Taber, 1997; Bodner, 1991; Kind, 2004; Lewis, 1996; Thomas & Schwenz, 1998; and references therein). Most notable is the CARD (Conceptual and Reasoning Difficulties) website (http://www.card.unp.ac.za) which attempts to compile relevant links to references, summaries of research and remedial strategies.

Some origins of misconceptions may be broadly categorised into the following:

i Present understanding of chemical knowledge is inadequate to explain concepts.
ii Over-simplifications of concepts to facilitate understanding.
iii Bad chemistry
iv Vernacular misinterpretations of concepts.

PRESENT UNDERSTANDING OF CHEMICAL KNOWLEDGE IS INADEQUATE TO EXPLAIN CONCEPTS

During the Ionian Period between 600-500 BC, philosophers such as Thales (585 BC), Anaximander (555 BC), Anaximenes (535 BC), and Heraclitus (500BC) sought materialistic explanations for the Universe without making any reference to supernatural explanation. Such explanations were purely based on observations without experiments.

The Greek philosophers, the so-called thinkers, propounded many theories to describe the universe and natural phenomena. Aristotle, for example, proposed that the elements of the universe comprises just four elements, namely, air, fire, earth, and water from which all other elements may be derived.

Plato (Socrates's student) believed in *Divine Intelligence* and represented matter as regular polyhedrons, for example, fire with a tetrahedron, air with an octahedron, water with an icosahedron and earth with a cube. The closest to modern definition of an atom was made by Democritus (460–370 B.C.) who proposed that matter was made of discrete indivisible particles, which he called *atomos*, meaning "cannot be cut." However, his ideas were largely ignored until the scientific revolution of the 16th, 17th, and 18th centuries.

They were good science then; the same may be said of modern chemistry. We are undergoing dynamic changes all the time. This explains the many theories on bondings, namely, the valence bond theory, the crystal field theory, the ligand field theory, and the molecular orbital theory; and the revised definitions of acids and bases, which are a few of such examples. Students may find it confusing at times. They are taught that electrons revolve around orbitals and at the same time they can be found anywhere near the nucleus. What do you mean when you speak of atomic radius and ionic radius?

OVER-SIMPLIFICATION OF CONCEPTS TO FACILITATE UNDERSTANDING

It is often difficult to explain something which is not visible and has little or no accurate semblance to reality. In attempting to illustrate a chemical bond between two atoms, two spheres are erroneously connected together by a line which is supposed to represent a bond.

Electrons are neatly arranged in spheres representing shells and sub-shells with ‘magic number’ of 2, 8, 18, 32 electrons. We can explain these numbers in terms of quantum numbers but again are we not introducing more ‘confusion’ to the students keeping in mind that they need to cover the examination syllabus within a set time frame? There are many examples of ‘misrepresentations’ of chemical ideas in secondary text books which are often introduced as analogies to explain certain concepts. In the process, students are often led to develop wrong impressions. Electron density surfaces are represented by spherical, dumb-bell shape, and clover-leaf shape orbitals. Many students believe that electrons really occupy such shapes. Such misrepresentations are ‘necessary misconceptions’ without which students may find it difficult to understand and discuss orbital overlap in chemical bondings. We can quite easily represent bonding using diagrams but how do we represent anti-bonding? Students at A-level need not understand the mathematics behind the ‘orbital’ representations to discuss the symmetry and overlapping of orbitals.

A dilemma has therefore being created; to teach the ‘correct’ chemistry and make students more confused or to introduce wrong concepts to them for the sake of passing examinations.

BAD CHEMISTRY

This arises mainly from teachers who do not have a good understanding of chemical principles, or the teacher himself is unaware of the misconceptions. Few attempts (Kevin Lehmann, 1996) have been made to identify these which may be attributed to the difficulty in assessing teachers.

It is often difficult to know what we do not know unless it is made known either directly or otherwise. Teachers may carry with them wrong chemistry concepts and may never realise it. A constructivist teaching approach involving new ideas and open discussions will certainly help to identify such misconceptions. However, this is hardly practised, not in this Region at least where an objectivistic paradigm is more appropriate for the teaching of science. Objectivistic approach has traditionally been practiced here mainly because students have not been brought up to ‘inquire’ but rather to accept whatever is taught to them with much emphasis on keeping within the frame-work of the syllabus. Basically, they are examination-smart but lack the confidence to seek information.

VERNACULAR MISINTERPRETATIONS OF CONCEPTS

Owing to the diversity in culture and language, perceptions can differ quite significantly among students. These could be a result of misinterpretation of text, beliefs (O’Connell, 2001), or vernacular translations; the latter is relevant to Asian countries where English is not the mother tongue and having a more diverse cultural background compared to the western culture. This is significant largely because most of these texts are from the Western world and are quite different from that viewed from an Asian perspective. The switch from English to Bahasa Malaysia and back to English has indeed produced much confusion to the students in Malaysia. A grain of sodium may be translated as a ‘biji’ of sodium in Bahasa Malaysia; a coconut is also called a ’biji’ of coconut. The implication can be quite catastrophic!

Hydrolysis is sometimes called 'uriair' which literally means splitting of water; perhaps, this term is better reserved for the electrolysis of water.

SURVEY

Identification of Students' Misconceptions

A survey was conducted on some secondary school students and teachers from Singapore and Malaysia. The purpose is to identify misconceptions among students of different cultural and vernacular backgrounds.

1. Method

It is difficult to identify students' misconceptions in chemistry (Horton, 2004). To understand the misconceptions among students in Singapore secondary schools and Junior Colleges, questionnaires were sent out to assess their understanding of chemical concepts. The objective was primarily to identify their perception of chemical principles. A sample size of 90 students from secondary schools and 80 from Junior Colleges were used. No breakdown was carried out on the number and the way students answered the questions, rather a compilation was made to identify the type of misconceptions.

2. Results

A sample of the questionnaire is given in Table 1 together with the general misconceptions identified.

Table 1: Sample of Questions Used & Misconceptions Identified

Questions	General Misconceptions
Atoms	
How would you represent an atom?	Atoms are small spherical particles which are all the same; their number distinguishes the different elements.
How are electrons arranged around the nucleus?	Atoms are like the sun with electrons (planets) revolving around it in definite paths.
How do you define the size of atoms?	Atoms are spheres having a definite radius but they cannot define atomic radius.
Molecules	

How do you visualize molecules?	Molecules are made up of atoms held together either by ionic or covalent bonds.
What happens to molecules when they are heated?	Molecules expand when heated and become soft.
Chemical Bonds	
How are atoms held together in the formation of chemical bonds?	Atoms are attracted to one another and then form either ionic or covalent bonds.
What is an ionic compound?	An ionic compound has atoms held together with one atom giving an electron to another.
What is a covalent compound?	A covalent compound is one where each atom contributes one electron each to form a covalent bond.
How do you represent a molecule of sodium chloride?	A molecule of sodium chloride is represented by NaCl where a sodium atom donates one electron to a chlorine atom.
If sodium chloride is ionic, does solid sodium chloride conduct electricity?	Electrons can move between ions and can therefore conduct electricity.
Chemical Bonds –Ionic	
Show how you represent a molecule of sodium chloride and a molecule of MgO.	Ionic molecules like NaCl and MgO are discrete units.
What happens when NaCl is dissolved in water?	Na^+Cl^- bonds are not broken in dissolving; only inter-molecular bonds are broken. This explains why we can recover NaCl when water is removed.
Chemical Bonds –Covalent	
How would you represent a covalent bond? Draw the Lewis diagram for CCl_4.	Electrons forming the covalent bond are identifiable and are equally shared between the two bonding atoms.
Why does aqueous HCl conduct electricity?	HCl is an ionic compound because it conducts electricity in water.
Classify the following compounds as ionic or covalent: $AlCl_3$, LiBr, LiF.	A covalent compound does not exhibit ionic character and an ionic compound consists of ionic particles only.

Chemical Reactions	
Which compounds are considered soluble and which are insoluble: sugar, calcium carbonate, sodium sulphate, wax?	A compound is soluble if it can dissolve in water. Solubility is used without considering solvent, amount used and temperature.
What happens when an aqueous solution of sodium chloride is mixed with a solution of aluminium nitrate?	Nothing happens, hence there is no reaction.
What happens when the solution is concentrated and cooled?	On cooling, the sodium chloride and aluminium nitrate will be recovered.

Identification of Misconceptions Imparted by Teachers

1. Method

A study was conducted with active teacher participation. Each teacher was required to give a half-hour micro-lesson on a topic they had taught in school. The other participating teachers were required to play the role of students; having no prior knowledge of the subject and asking questions for clarifications from time to time. They also tried to figure out the type of misconceptions that could have developed directly or indirectly from the lessons.

Misconceptions imparted by the teachers or preconceived beliefs by students, were identified after each lesson. Post conferencing involving all participants were conducted after each session and topics discussed in greater details. Misconceptions that could have been introduced or developed during the lessons were identified after every lesson.

2. Results

The two years survey of 20 teacher participants each year, produced some very useful results and are tabulated in Table 2.

Table 2: Some Erroneous Perceptions and Queries

Na^+ and Cl^- ions can have independent existence and can exist separately.
$AlCl_3$ is a more ionic compound than NaCl because aluminium has a higher positive charge than sodium.
Carbon tetrachloride is a polar compound because the C-Cl bonds are polar.
Lithium chloride is ionic but is more covalent than sodium chloride. How can a compound be covalent and ionic at the same time?

Hydrochloric acid is an ionic compound because it can be used as an electrolyte.
When silver nitrate is added to a colourless solution and a white precipitate is formed then the solution must contain chloride ions.
A salt bridge helps to complete the circuit by allowing electrons to flow through.
Covalent bond means strong bonding between atoms and therefore HI which has a stronger covalent bond should be a weaker acid than HF. The stronger acid strength in HI is largely due to stronger H-bonding in HF as compared to HI.
When two reagents react, as depicted in a chemical equation, it is not perceived that one must necessarily be in excess. Also, there are no other reactions possible other than those shown in the equation.
In the esterification reaction, the condensation involves the removal of a water molecule with the hydroxyl group coming from the alcohol and the proton coming from the carboxylic acid.
In molecules such as $[CuSO_4.6H_2O]$ the sulphate is linked to the metal atom by a bond through the sulphur atom and the water molecules arranged at random around the $Cu(SO_4)$ “nucleus’’. In $[Co(NH_3)_3Cl_3]$, the $CoCl_3$ is surrounded by 3 ammonia molecules.
Physical changes are reversible while chemical changes are not.
When two soluble salts are added together, a double displacement reaction will always occur resulting in the formation of two salts. Also, if two solutions containing A^+X^- and B^+Y^- are added together an insoluble precipitate is always formed?
Given the half-reactions, Mn(II) $\rightarrow$ Mn(IV) E^0 (1) and Mn(IV) $\rightarrow$ Mn(VII) E^0 (2), the Mn(II) $\rightarrow$ Mn(VII) E^0 (3), For redox reactions, the electro potential, E^0 values are additive i.e. $E^0 (3) = E^0 (1) + E^0 (2)$.
The heat of formation of water from the neutralisation reaction depends on the strengths of the acid and base used. $NaOH + HCl \rightarrow NaCl + H_2O$ and $NH_4OH + HCl \rightarrow NH_4Cl + H_2O$.
The 2 electrons removed come from the d orbitals and not the s orbitals because they are further away from the nucleus. For example, since the electronic configuration of iron is $[Ar]3s^2\ 3p^64s^23d^6$, then the electronic configuration of Fe^{2+} is $[Ar]3s^2\ 3p^64s^23d^4$

When there appears to be no change in a chemical reaction, the chemical reaction has stopped completely and a static condition is reached.
The order for the reaction, aA + bB → cC + dD, is given by (a + b).
All acids are donors of H^+ and bases are donors of OH^- ions.
All triatomic molecules are linear, tetra atomic molecules are trigonal planar and pentatomic molecules are tetrahedral in shape.
All blue coloured compounds must contain copper ions. It is blue because it absorbs light in the blue region of the spectrum.

DISCUSIONS

From the above results, the following observations are made.

- Some teachers realised that they have been teaching some wrong concepts to students for years without being aware of them. I had a student who was awed to realise that she has been teaching the same wrong concept for the past six years!

- Many found that they believed they understood the concepts quite well when in fact they only had a hazy idea and were not so sure of the concepts. This invariably leads to further confusion. Some of these are found in the questions set under Table 2.

- They did not realise that the students were not 'seeing' or conceiving the ideas the way they wanted the students to perceive. This became apparent when they played the role of students.

- Some analogies used for explaining concepts were not very appropriate and often mislead the students' understanding. This is quite common for it is not easy to draw similar parallels between two completely unrelated phenomena. More ambiguities may be introduced in the process. A teacher, in attempting to explain the increased strength of iron when impregnated with carbon atoms, used a stack of pencils to represent the iron atoms and a pen of thicker diameter to represent a carbon atom. The analogy was poor because the stack became more loose instead of being strengthened by the packing. This illustration probably explains the property of solder better.

- The teachers became more aware and conscious of what they were teaching, taking care not to mislead the students.

- By playing the role of the students, teacher participants appreciated the problems that students face, such as sequence of thoughts and coherency. For example, there is H-bonding between water molecules therefore it has higher boiling points and not because it has higher boiling point therefore it has H-bonding. To teach students the properties of elements before discussion of electronic configurations often lead students to memorise dull facts rather than familiarise them with group trends.

The teaching of chemistry has traditionally been based on the objectivist view of knowledge; a largely teacher-centered approach where the students learn through rote learning and assessed through ability to regurgitate facts. This is particularly true in Singapore and Malaysia where the educational system is built largely from a British model; assessed mainly through an exclusively examination-based model. Students are trained to answer examination questions from past years with little or no emphasis on a constructivistic approach (Coll & Taylor, 2001). This is not surprising since the A-level Chemistry examinations are based on a broad syllabus where students have to answer five question papers over a period of two years in the United Kingdom, one and a half years in most private colleges in Malaysia and some even within fifteen months! A paradigm shift to a more constructivist view of learning has met with much difficulties and criticisms, and certainly not very practical in the Malaysian context.

It is often difficult to identify misconceptions in students unless discussions and questionnaires like those above are conducted periodically. It is even more difficult to identify misconceptions in teachers unless they are identified through self-study, questionnaires and upgrading courses. Their perceptions of chemical concepts are more entrenched and they are not so ready to accept alternative explanations.

REFERENCES

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

Coll, R. K., & Neil Taylor, T.G. 2001. Using constructivism to inform tertiary chemistry pedagogy. *Chemistry education: Research and practice in Europe*, 2(3), 215-226.

Douglas Mulford. 1996. An inventory for measuring college students' level of misconceptions in first semester chemistry, Purdue University.

Griffiths, A. K., & Preston, K. R. 1992. Conceptual difficulties experienced by senior high school students in electrochemistry: electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching,* 29, 1079-1099.

Horton, C. 2001. *Students Preconceptions and Misconceptions in Chemistry*. Retrieved from <http://www.daisley.net/hellevator/misconceptions/misconceptions.pdf>

Kevin Lehmann, 1996. *Bad Chemistry*. Dept of Chemistry, Princeton University. Retrieved from <http://www.princeton.edu/~lehmann/BadChemistry.html>

Kind Vanessa. 2004. *Beyond Appearances: Students' misconceptions about basic chemical ideas.* 2nd Edition, School of Education, Durham University, UK.

Mulford, D. R., & Robinson, W. R. 2002. An inventory for alternate conceptions among first-semester General Chemistry students. *Journal of ChemicalEducation,* 79 (6), 739-744.

Novick, S., & Nussbaum, J. 1981. Pupils' understanding of the particulate nature of matter: A cross-age study. *Science Education,* 65 (2), 187-196.

O'Connell, Joe. 2001. *Salt Myths and Urban Legends*. Retrieved from <http://www.scbbqa.com/myths/Salt.html>

Taber, K. S. 1997. Student understanding of ionic bonding: Molecular versus electrostatic framework? *School Science Review,* 78, 85-95.

Thomas, P. L., & Schwenz, R. W. 1998. College Physical Chemistry students' conceptions of equilibrium and fundamental thermodynamics. *Journal of Research in Science Teaching,* 35 (10), 1151-60.