The purpose of this article is to highlight the concern that some of the big ideas in chemistry seem so elusive to many of our chemistry graduates and to suggest that the big ideas of chemistry must be emphasized in the process of instruction.

According to Einstein (1954: 293), 'The aim of science is, on the one hand, a comprehension, as complete as possible, of the connection between the sense experiences in their totality, and, on the other hand, the accomplishment of this aim by the use of a minimum of primary concepts and relations'. These primary concepts and relations are referred to as the generalizations governing the behaviour of the natural world by Chalmers (1990) in his discussion on the aim of science as the establishment of these generalizations. Concepts are hence both the products of scientific enterprises and basis for science learning as well as for scientific pursuits.

Over the past several years, a module on assessment in chemistry is taught to successive batches of graduate students who are enrolled in a one-year post graduate diploma in the education course at our institute. The course is aimed at preparing these graduates to teach at least two academic subjects in the secondary school curriculum, one of which is chemistry.

**The Elusive Mole**

In this module the rules of writing multiple choice items were discussed, with each rule illustrated by specific examples of weak or faulty items. Students were then given a take-home assignment in which they are presented with multiple choice questions which are 'faulty' in some way and which require 'modifications' or 'improvement' in some way or another. The following is one such item:

Which one of the following statements about the formation of ionic compounds is not correct?

A. MgO Four electrons are transferred.
B. Al₂O₃ Six electrons are transferred.
C. CaCl₂ Two electrons are transferred.
D. NaCl One electron is transferred.
Many students could only suggest improvement of the item in terms of formatting, or reorganization of the information presented in either the stem or the options or both. A typical ‘improved’ item is as follows where the information given in the options is reorganized by tabulation.

Which one of the following options about the formation of ionic compounds is not correct?

<table>
<thead>
<tr>
<th>Option</th>
<th>Ionic Compound</th>
<th>Number of electrons transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>MgO</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>Al₂O₃</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>CaCl₂</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>NaCl</td>
<td>1</td>
</tr>
</tbody>
</table>

Many students could not see that the main weakness in the given item is that the concept of mole is missing in both the stem and the options, which in turn suggests that the vast majority of the students have not internalized the mole concept.

This is rather surprising since the mole concept is a core concept in chemistry, and is included in the syllabus from secondary three and is reinforced from then onwards every year through Advanced Level to university level.

It would have been reasonable to expect a graduate in chemistry to be able to suggest an improvement in the following terms:

Which one of the following options about the formation of one mole of ionic compounds is not correct?

<table>
<thead>
<tr>
<th>Option</th>
<th>Ionic Compound</th>
<th>Number of moles of electrons transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>MgO</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>Al₂O₃</td>
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<td>1</td>
</tr>
</tbody>
</table>

**THE MISSING SERIES**

After having discussed guidelines for drafting mark schemes, the class was requested to draft mark schemes for questions which test basic
concepts in chemistry. Some of these questions are taken from past years' Cambridge 'O' level examination papers. An example of such a question is as follows:

*Explain the meaning of the words alkane and alkene.* [4 marks]

Here in this question, one would consider that the concept tested is the one major theoretical concept in organic chemistry, i.e. the concept of 'homologous series', together with an understanding of the differences between the two homologous series named in the question.

Hence one is surprised to find that many students do not include the concept 'homologous series' in their mark schemes. Instead, they approach this question by stating the most prominent characteristics, such as:

- alkanes are straight chain or branched chain hydrocarbons with only single bonds [1 mark]; they have the general formula: \( C_nH_{2n+2} \) [1 mark]; whereas
- alkenes are straight chain or branched chain hydrocarbons with one C—C double bond [1 mark]; they have the general formula: \( C_nH_{2n} \) [1 mark].

A more acceptable mark scheme would have been as follows:

- Each of the words refer to a 'homologous series' [1 mark]; both homologous series are hydrocarbons [1 mark]; the difference is that the word 'alkanes' refers to the homologous series of saturated hydrocarbons, that is, each carbon has a covalency of 4 or is bonded to 4 other atoms, while the word 'alkenes' refers to the homologous series of unsaturated hydrocarbons containing C=C bonds [1 mark];
- alkanes refer to the homologous series with the general formula \( C_nH_{2n+2} \) while alkenes refer to the homologous series with the general formula \( C_nH_{2n} \) [1 mark].

This latter mark scheme is preferred to the previous one because it includes the concept of 'homologous series' which is a more inclusive or generic concept than those concepts or generalizations mentioned in the former mark scheme.

The concept 'homologous series' is the concept word or global label which subsumes the following characteristics or factual statements:

- A family of organic compounds which follows a regular structural pattern, in which each successive member differs in composition by the
addition of a \(-\text{CH}_2-\) group. They have a general molecular formula. Each successive member differs in its molecular formula by the addition of a \(-\text{CH}_2-\) group, and its relative molecular mass by an increase of 14. The physical properties of the members change gradually as the number of carbon atoms per molecule increases. All members show similar chemical properties, although they vary gradually in reactivity along the series. All members can usually be prepared by the same general methods.

THE NEED TO EMPHASIZE THE BIG IDEAS IN CHEMISTRY TEACHING

The mole concept is fundamental in chemistry and is not only introduced early in the Secondary Three chemistry curriculum but also resurfaces throughout higher levels of formal chemistry learning. The concept of homologous series is fundamental and ubiquitous in organic chemistry. Yet these two concepts seemed to have eluded many of the students. What has gone wrong with our chemistry education? Have teachers failed to teach these concepts properly? Or have teachers failed to emphasize these big ideas in chemistry concept labels? Or have our students learned too superficially?

Students' lack of grasp of the big ideas can perhaps be addressed through the use of concept mapping, together with the incorporation of propositional statements built around these big ideas. Concept mapping as advocated by Novak and Govin (1984) typically have a hierarchical structure, working downward from general to more specific ideas with appropriate relationship linkages along the way. Basic to making a concept map for a piece of scientific knowledge is the ability of a mapper to identify and relate its salient concepts to a general, superordinate concept. The concept mapper must often transform the knowledge to be mapped from its current linear form to a context-dependent hierarchical form. Before that the mapper must identify the key concepts, arrange them from general to specific and relate them to each other in a meaningful way. This technique enhances meaningful learning by leading students 'away from rote learning and toward true understanding of concepts and their relationships' (Ault, 1985). Thus when students are trained in concept mapping, it is less likely for the big ideas to elude them.

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REFERENCES


