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Making Thinking Visible in Chemistry Through Analogies and Models

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Abstract

Teachers and their students can clarify abstract ideas in chemistry using analogies and models, both conceptual and physical. The use of analogies and models allows individuals to make their thinking and understanding of complex ideas visible to both themselves and their peers. Once thinking and understanding of complex ideas has been made visible, then discussions can take place with more clarity and potential misconceptions can be addressed. When students take things that are precise and familiar to them in the macroscopic world and reconcile them with things that are abstract and unfamiliar in the sub-microscopic world, then the cognitive effort required to form connections facilitates deeper learning and understanding of the abstract concepts.

Introduction

A significant number of students find aspects of chemistry difficult to learn, and from a teacher's perspective, it is a complex subject to teach. Fensham (2005) proposes that this is because chemical knowledge is created by professional chemists for use by professional chemists and, as such, it is not easily accessible and useful to secondary school students. In addition, Fensham (2005) suggests that students' enjoyment of learning chemistry is diminished because it is often taught in a didactic manner, the content is not immediately relevant to the students' lives and – compared to other subjects – it is difficult to learn. Consequently, it is important for chemistry teachers to transform and present chemical knowledge into a form that is accessible, interesting and useful to their students.

McComas (2017) identifies another challenge to science teachers in general – why teach science when only a small percentage of secondary school students will enter professions that require a high degree of scientific knowledge? To answer this question, it should be remembered that science is more than a collection of facts, it is a body of knowledge (concepts, theories and laws) it is a way of thinking (curiosity, reasoning and scepticism) and it is a way of investigating (inquiring, observing and concluding) –

important cognitive skills that are relevant to all members of society regardless of their career path.

In summary, it is the role of the chemistry teacher to transform difficult concepts used by professional scientists into a form that is accessible, interesting and useful to their students. This is significant because scientific literacy is important in personal decision making and is therefore a benefit to society. One way to achieve this if for both teachers and students to make their thinking visible through the use of models and analogies, a process that helps to clarify understanding and reduce misconceptions in the classroom.

Literature review

> "In learning abstract science concepts, if teachers could use pedagogical approaches that allow students to visualise the concepts, this will prompt students to have a better understanding of the concepts."
>
> Karpudewan *et al.*, 2017.

Learning takes place when a person in cognitive equilibrium encounters new knowledge. Cognitive disequilibrium then occurs as the individual connects and assimilates the new knowledge with what they already know. As new schemata, or knowledge structures, are formed, the individual returns to cognitive equilibrium (Jean Piaget, 1936). It is proposed that if new knowledge is presented to students through a context that they are already familiar with (*i.e.* using analogies and models) then the new knowledge will be more easily assimilated into the students' existing knowledge.

Learning is a consequence of thinking (Clark and Linn, 2003). Learning improves when students are able to think through the concepts that they are studying, a process that takes time and energy and requires varied activities and many opportunities to make connections. In addition, good thinking (and hence learning) requires students to be open-minded, curious, sceptical and imaginative (Perkins and Ritchhart, 2004). Without these characteristics, good thinking will not take place and only shallow learning will occur (Hattie and Yates, 2014).

In order for students to learn chemistry, they must be able to think through the concept that they are studying, but if they are unable to imagine what is taking place at a molecular level, shallow learning will occur and misconceptions will accumulate. It is therefore important for chemistry students to make their thinking and learning visible so that they can reflect on their own work and so that it can be evaluated by their peers and their teachers.

The Chemistry Triangle proposed by Johnstone (1991) illustrates his proposal that students must understand three different domains of chemistry. He suggests that many teachers begin with the macroscopic domain, with their students conducting experiments that have observable outcomes. They then proceed to the representational domain, where students write balanced chemical equations in order to describe the reaction. Finally, they arrive at the sub-microscopic domain where the potential for misconceptions arises as students start to make sense of how and why chemical changes take place at the scale of atoms, ions and molecules.

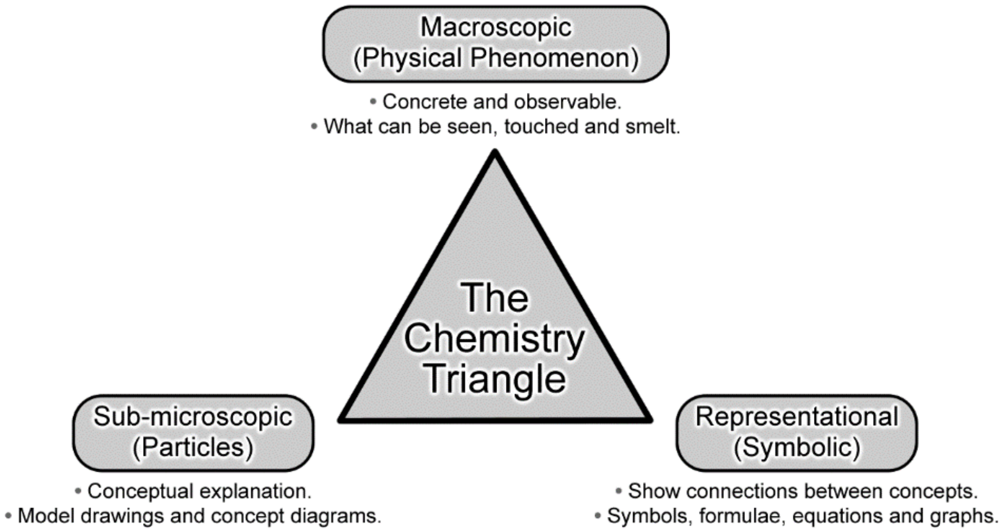

Figure 1. Johnstone (1991) proposed that students must understand three different domains of chemistry, macroscopic, representational and sub-microscopic.

Examples of Students' Misconceptions

A key issue with teaching and learning chemistry is the abstract nature of the subject. Teachers can demonstrate, and students can observe, the consequence of a chemical reaction, for example, a change in temperature or the production of a gas, but it is impossible to observe the actual particles as they react. Teachers may struggle with explaining what cannot be observed and students can become frustrated as they try to imagine what might be happening at a molecular level. This combination has the potential to create misconceptions in the mind of the student and a difficulty in learning the subject.

What a teacher tells and shows their students, and what their students conceptualise and understand do not always match. Based upon their own experiences and tacit knowledge, as a student reconciles new information with what they already know, misconceptions can arise. These can persist and may manifest new misconceptions in other areas of chemistry if the student is not given the opportunity to make their thinking and understanding visible.

Some examples of students' misconceptions are given below. Note that they are both misconceptions about events that occur at the sub-microscopic level. The first example (**Figure 2.**) shows a student's understanding of sodium chloride dissolving in water, which the student has interpreted literally by drawing a sodium ion and chloride ion *inside* a water molecule. The second example (**Figure 3.**) shows a student's understanding of a particle in the gas phase moving through a vacuum. The student has drawn the particle moving randomly, rather than in a straight line, even though there are no other particles for it to collide with.

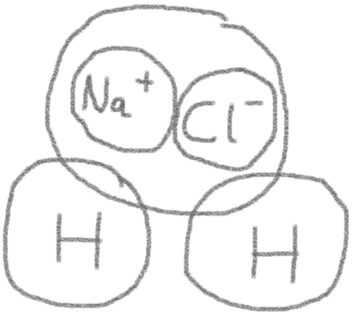

Figure 2. A student's understanding of sodium chloride dissolved in water.

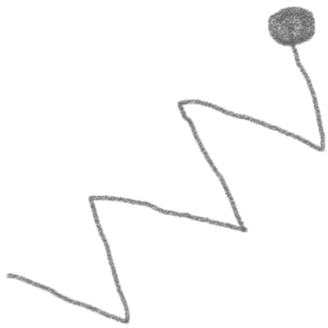

Figure 3. A student's understanding of a single particle moving through a vacuum.

Other common misconceptions that need to be addressed are evident when students use the terms '*dissolving*' and '*melting*' interchangeably, and when students use the terms '*boiling*' and '*evaporating*' almost randomly within the same sentence.

Classroom Strategies for Making Thinking Visible

1. Harvard Project Zero thinking routines – I used to think… …now I think. This is a popular thinking routine that can be used to show how a student's understanding of a topic has changed as a result of teaching or some other new experience. The student begins by describing what they *used to think* about a topic. The student then describes how their thinking has changed after learning something new, for example, after watching a video, conducting an experiment or participating in a class discussion. Note that is useful to question the students further to uncover *why* their thinking changed, for example, what information or experience had a significant impact on their understanding of the topic?

A student reflects upon what they think an acid is based upon what they have read in the news and seen in films (media influence):

"*I used to think that acids were dangerous, corrosive liquids that dissolved everything*."

The student then reflects upon what they think an acid is after studying and conducting experiments on acids, bases and salts:

"*Now I think that acids are chemicals that produce hydrogen ions. They can be neutralised by bases, and some acids are even safe enough to eat*."

Figure 4. Modelling a molecule of methane, CH_4, using circular magnets on a whiteboard.

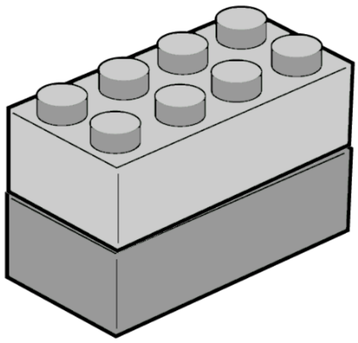

Figure 5. Modelling a diatomic molecule of a compound using LEGO®.

Figure 6. Modelling a compound in the solid state using M&Ms®.

2. Circular magnets of different colours can be attached to a classroom's whiteboard and used to model atoms of different chemical elements (**Figure 4.**). This is a very visual approach to teaching students how to balance chemical equations. Students stand at the whiteboard adding and moving magnets as necessary, under the scrutiny of their peers, until the chemical equation in question has been balanced. Throughout the process, students are encouraged to explain their thinking aloud to the class. This serves as a form of *metacognition*, and allows their peers to follow their decision making, thus providing material for a brief class discussion once the task is complete.

3. Most students are familiar with LEGO®, and they are keen to construct models of sub-microscopic concepts in chemistry using LEGO® bricks, making their thinking and understanding very visible in the process. The bricks can be used by students to model elements, compounds, mixtures of elements and mixtures of compounds (**Figure 5.**). At a higher level, the bricks can also be used to model polymerisation and optical isomerism. Through visual inspection of a student’s model, teachers and their peers can quickly assess the level of understanding and identify potential misconceptions.

4. M&Ms® are small, circular candies that are available in many different colours. If each colour is assumed to represent a different chemical element, then students can quickly arrange M&Ms® to illustrate elements, compounds and mixtures as solids, liquids and gases (**Figure 6.**). Students can photograph their models and share them in an online document for peers to evaluate and comment on, making their thinking visible, and making learning more engaging and dynamic.

5. My favourite mistake! This activity begins with the teacher setting their students a short problem to solve, for example, drawing a dot-and-cross diagram of a chemical compound or completing a mole calculation. Students answer the question on small pieces of paper which the teacher collects. While the students are focussed on other learning activities, the teacher quickly reviews their students’ answers until they find their ‘*favourite mistake*’ which maybe a common error or misconception. The teacher re-writes the inaccurate answer (in order to hide the student’s identity) and then projects it on a screen for the whole class to see. The teacher then invites their students to identify what is good about the answer (what should be praised) before moving onto the error(s), concluding with a discussion about how and why the error(s) could have arisen.

Discussion / Conclusion

General feedback from students, collected in a qualitative manner, is that they enjoy learning chemistry through analogies and models. Students feel confident taking ideas that they are already familiar with and using them, through analogies, to explore and define abstract concepts that would be difficult to understand in isolation. In addition, encouraging students to come-up with their own analogies to explain abstract concepts in chemistry fosters critical and creative thinking which are important and enduring skills for students to learn.

Encouraging students to make their thinking visible by using physical models appeals to students who are kinaesthetic and visual learners. Students seem (assumption) to be more willing to take responsible risks when expressing their thinking using models rather than just words. Referring to a physical model while explaining their reasoning can provide students with more confidence and focus as it provides them with something to structure their answer around.

One word of caution, although analogies and models can help students to make their thinking visible and understand concepts, they must still be able to describe their thinking using the correct scientific terms (scientific literacy) – which is another thing to be mastered and something that is still a problem for some individuals.

Further reading

http://www.scientist.sg/visible_thinking/visible_thinking.htm

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