education in chemistry

Drawing boosts understanding

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Get your students drawing diagrams to help them get to grips with chemical concepts

Many chemical concepts can be represented in more than one way, each providing different information. For example, the structure of a molecule can be represented as a formula, a 2D structural drawing, a ball-and-stick model or a space-filling model. These multiple representations are often a source of confusion for students.

Multiple representations

In some cases, we present students with preconstructed diagrams to interpret. These can be of scientific equipment to support practical work, for example, or particulate-level diagrams to help students link the macroscopic and sub-microscopic domains.

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Do your students understand the hydrogen bonding in a snowflake? Why not get them drawing to find out

When students create diagrams themselves, it promotes the development of observational and reasoning skills. This can develop their mental models of science phenomena as they need to select key spatial features and represent them in a visual form. The development of these skills can be used as a means of assessment.

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While challenging, the use of multiple representations is beneficial to students. Each form has different characteristics that convey complementary information about a concept. Drawing diagrams helps students to construct, organise and communicate their understanding of these concepts. They can then navigate the challenge of accumulating fragmented knowledge, develop problem-solving strategies and construct a deeper understanding of complex science concepts.

The challenge of multiple representations is considerably greater when there are many different fundamental chemical concepts needed to explain another – the concept of hydrogen bonding in water, for example. How do you encode information about electronegativity, molecular shape, molecular orientation and lone pairs of electrons into a single diagram that forms a coherent explanation?

A new study by researchers from Australia and Taiwan answers this question. In it, they use student-generated diagrams to investigate students' conceptual understanding of the nature of hydrogen bonds between water molecules in snowflakes.

Teaching tips

- Students should be encouraged to draw diagrams more often. It can reveal students' mental models and potential alternative concepts.
- Diagrams could be particularly useful for students who haven't mastered the right scientific terminology, as they provide another way for them to communicate their understanding.

- You can use the interview prompts from the published paper in your own practice to assess your students' understanding of hydrogen bonding. You could also use them as a guide to develop your own prompts for other chemistry concepts.
- This research suggests that educators should be aware of challenges around understanding the directionality of hydrogen bonding, due to the position of the lone pairs of electrons and the position of the hydrogen atom. You can find more conceptions about hydrogen bonding in the paper.

An intermolecular challenge

The researchers used a series of scaffolded prompts to interview first and second year university students. These prompts slowly reminded students of the idea of hydrogen bonding in a snowflake, and built up to an explicit prompt to illustrate a system of multiple hydrogen-bonded water molecules in a diagram.

The diagrams from 60 of these interviews, and interview transcripts, were analysed using an inductive approach, generating different categories relating to the students' conceptions of hydrogen bonding in a snowflake. The analysis exposed several difficulties that students face, and new alternative concepts about hydrogen bonding.

Most students were able to adequately represent the bent structure of a water molecule in their diagrams and indicate the covalent nature of the intramolecular bonds. However, the diagrams revealed that students conceptualised the intermolecular hydrogen bonds in different ways.

Student-generated drawings were successfully used to interrogate students' conceptual understanding

Half of the students' diagrams illustrated the concept of a hydrogen bond correctly, including evidence of it being intermolecular, electrostatic and directional. However, the other half revealed alternative conceptions about the structure of water, the nature of intermolecular interactions and the specific involvement of lone pairs of electrons. For example, some students' diagrams suggested that the oxygens of two different water molecules could hydrogen bond to the same hydrogen.

Other students' diagrams suggested that both lone pairs of electrons on oxygen could collectively participate in a single hydrogen bond, without the need for precise directionality.

Even the diagrams which illustrated a sound understanding of hydrogen bonding showed that students struggle to represent molecular interactions in 3D. Hydrogen bonding is an abstract concept which is fundamental in chemistry. A coherent understanding depends on a good understanding of molecular shape, electronegativity and the distribution of electrons in molecules. So the researchers successfully used student-generated drawings about hydrogen bonding in snowflakes to interrogate the students' conceptual understanding.

A post-16 task using mini whiteboards

You could use the methods applied in the study as a post-16 class activity with mini whiteboards.

- Begin by showing students some magnified images of snowflakes and ask what they notice about their shapes.
- Get students to draw a single water molecule in the middle of their whiteboards, and show them to you.
- Discuss misconceptions, ensuring that all students finish with the correct V-shaped geometry.
- Ask them to add a second water molecule, showing how it interacts with the first, including use of lone pairs and dipoles. Explain the reasons that underpin the interaction.
- Then ask students to draw as many water molecules interacting with the original one as possible. When they have completed the task, they should each have a total of four H-bonded molecules. Give extra praise to those who convey 3D information in their drawing.
- A common misconception is that hydrogen bonds are intramolecular bonds to hydrogen atoms. Ask students to clearly label the hydrogen bonds in their diagrams to eliminate this misconception.
- It's hard to convey the 3D arrangement of water molecules in a drawing, so try to have a model as a reference to illustrate the lattice.
- On completion of the task, students should be able to relate the crystalline nature of snowflakes to the sub-microscopic arrangement of water molecules.

References

H Matovu *et al*, *Chem. Educ. Res. Pract.*, 2022, **23** (DOI: 10.1039/d2rp00175f)