The challenges of word equations

Elizabeth Mountstevens describes the challenges of word equations and suggests ways to support students.

The challenges students face with balancing symbol equations are frequently discussed. Word equations receive comparatively less attention and are often assumed to be easier for students. However, they require the same conceptual understanding of reactions and the same knowledge of reaction types. What approaches can be used to support students with word equations?

What makes word equations challenging?

When students are learning about different types of reaction, they are often asked to complete the missing term in a word equation, for example:

sulfuric acid + sodium hydroxide → _____ + water

To complete this task successfully, students need the following knowledge:

- Equations represent chemical reactions.
- Chemical reactions form new substances.
- Sulfuric acid is an acid and sodium hydroxide is an alkali.
- When acids and alkalis react they produce a salt and water.
- There are lots of different examples of salts.
- Sodium hydroxide gives sodium _____ salts and sulfuric acid gives _____ sulfate salts.

There are three main barriers faced by students to completing word equations:

1. Misconceptions about substances and reactions.
2. High demand on working memory.
3. Lack of familiarity with chemical names.

1 Misconceptions about substances and reactions

Misconceptions about chemical reactions can arise from the use of the words 'reaction' and 'substance' in everyday speech. If I react to a noise, the noise is causing the reaction but it does not cause a change. This can lead students to believe that one reactant causes the reaction in the other (Taber, 2012). Students also focus on observable features of the reaction such as colour change rather than the underlying rearrangement of atoms. Chemistry teachers define chemical reactions as something that forms a new substance. When chemists refer to a substance, they mean a single element or compound, whereas in everyday speech we use the word more generally to describe a material from which something is made.

Best Evidence Science Teaching (UYSEG, 2023) provides several useful resources to investigate and respond to students' misconceptions. One example from the chemical change section is shown in Figure 1. Only answer D suggests that two substances have reacted to form a new substance.

Colour change

Compound A and compound B are added to a small glass jar. Both compounds are white.

A lid is placed on the jar. The jar is shaken. A yellow colour appears.

Think about the following statements. Then tick the box to show how confident you are that each statement is right or wrong.

		I am **sure** this is right	I think this is right	I think this is wrong	I am **sure** this is wrong
A	A yellow substance has been released from the white powder.				
B	The white powder has changed colour.				
C	One of the white substances has changed into a yellow substance.				
D	A new yellow substance has been formed.				

BEST

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Figure 1 BEST resource to investigate students' misconceptions about chemical change produced by UYSEG, 2023

To reduce misconceptions about substances and chemical reactions we can:

- explain what chemists mean by the word substance using a Frayer Model (Box 1);
- use particle diagrams alongside word equations to show the rearrangement of atoms;
- use the BEST resources (UYSEG, 2023) to identify and correct misconceptions.

2 High demand on working memory

Working memory is the site of our conscious thinking. It only has a limited capacity so tasks that involve holding many things in mind will overwhelm working memory. Completing the missing term in a word equation requires a lot of knowledge and places a high demand on working memory. To reduce this burden, each component of the task needs to be practised so it can be done fluently before combining the elements together (Shibli and West, 2018). We can support students by designing a sequence of tasks that provides students with this practice.

Box 1 Frayer Models

A Frayer Model is a graphic organiser that can be used to help students to deepen their understanding of new vocabulary (Talbot, 2019). The traditional model contains a definition, characteristics, examples and non-examples. They are often adapted to include information on morphology and could be used to encourage deep thinking about groups of chemical substances. These Frayer Models, designed by the author, are for 'substance' and 'metal hydroxide'.

Substance	Definition: A substance is a single element or compound.	Use in a sentence: A pure sample contains only one substance.
Examples: Elements e.g. iron, oxygen and graphite Compounds e.g. salt (sodium chloride), sugar and carbon dioxide	Non-examples: Sea water Orange juice	Parts of the word: Sub – under Stance - thing

Metal hydroxide	Elements: Metal e.g. sodium calcium iron hydrogen oxygen	Examples: Sodium hydroxide, NaOH, in oven cleaner Magnesium hydroxide, $Mg(OH)_2$, in limewater Iron hydroxide $Fe(OH)_2$ in rust
Properties: Alkalis Greater than pH 7	Made by: Sea water Orange juice	Reacts with: Sub – under Stance – thing

For example, for the reactions of acids:

1. Keep the acid the same and name the salts for different alkalis.
2. Keep the alkali the same and name the salts for different acids.
3. Name the salts for different combinations of acids and alkalis.
4. Fill in the name of the salt in a word equation.
5. Complete word equations for different acids and alkalis.
6. Fill in the missing term in an equation.

To support students with the demands on working memory:

- Give students the opportunity for lots of practice with individual reactions.
- Use retrieval practice to revisit each type of reaction.
- Model how to identify the type of reaction from the information given.

3 Lack of familiarity with chemical names

One of the advantages of symbol equations is the ability to see the elements in the reactants and check for their presence in the products. With word equations that information is hidden from students who do not know the elements in a substance. One way to support students is to include symbol equations alongside the word equations (Taber, 2012). This will increase the demands on working memory initially but could be mitigated by focusing attention on each part of the equation in turn and linking the symbols to the periodic table. A better understanding of the components of different chemical substances should actually reduce the demand on working memory of writing word equations in the long term.

Unfamiliar chemical names are likely to be a particular problem for students with lower literacy levels. Teaching chemical names in the way we would introduce new vocabulary provides a potential solution.

To support students to become more familiar with chemical names:

- Show balanced symbol equations alongside word equations.
- Introduce the different chemical names through a Frayer Model (Box 1).
- Revisit chemical names through retrieval practice.

Reflections on implementation

In the last year we have started to update our approach by incorporating some of these recommendations. When chemical reactions are introduced in year 7 (ages 11–12) we use a variety of representations (Figure 2) and the BEST resources. The number of students who achieved the highest 'Excellent' level on the end-of-topic test increased by 10%, although this figure could be affected by several different factors.

In year 8 (ages 12–13), when we look at *a variety* of different reactions, we have introduced more practice. While this did help students, their feedback is that they would like to work through the sections at their own pace. At the end of the topic students found it hard to complete equations

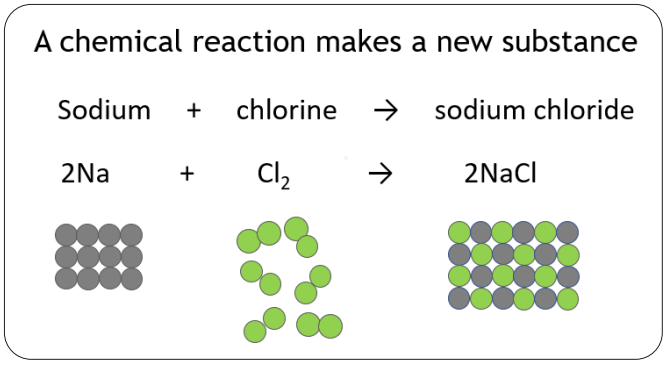

Figure 2 Slide created by the author to introduce chemical reactions using a variety of different representations

when the different types of reaction were mixed together because they were not confident identifying the type of reaction. Next year I aim to use a consistent approach when introducing new reactions: presenting the word and symbol equations simultaneously, using a Frayer Model (Box 1), providing them with the opportunity for guided practice to support them to become more familiar with the different types of reaction.

Useful links

Best Evidence Science Teaching resources:
https://www.stem.org.uk/secondary/resources/collections/science/best-evidence-science-teaching

Chemical misconceptions: Prevention, diagnosis and cure:
https://edu.rsc.org/resources/chemical-misconceptions/1967.article

References

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UYSEG (2023) *Big Idea: Chemical Reactions*. University of York Science Education Group. https://www.stem.org.uk/secondary/resources/collections/science/best-evidence-science-teaching/chemical-reactions

Elizabeth Mountstevens is a teacher of science at Sir John Lawes School and a member of the ASE Research Committee.
✉ emountstevens@sjl.herts.sch.uk
𝕏 @DrMountstevens