Martin Wesley discusses misconceptions commonly seen when teaching science and some strategies to pre-empt or correct them

Figure 1 Making simple circuits using solar cells to correct the colloquial use of 'battery'

Add more gin!

Common misconceptions and strategies for correcting them

This article was prompted not by erroneous teaching but by misconceptions that children have picked up somewhere and that my colleagues and I have encountered again and again when delivering practical science workshops in schools. Our company covers the whole of the UK and, since it was formed in 2000, has delivered over 20,000 workshop sessions. I will present some of the most common misconceptions we have come across, explore why they are misconceptions and suggest a few strategies for teachers to either pre-empt or correct them.

Scientific literacy

Many misunderstandings arise for young learners because of a difference in the meaning of words and phrases in colloquial and scientific usage. The word used for an item at home may not be the same as that used in a science lesson; alternatively, a familiar word may appear in a textbook but have a different meaning. Neither use is 'wrong' as, essentially, the meaning of the same word differs according to the context. Unlike other colloquialisms, however, the same words have allied but divergent meanings and so misunderstanding can easily be created in the mind of the young learner. Developing this scientific literacy is key to supporting learning. For example, colloquially 'freezing' means 'very cold' as in '*The classroom is freezing because you left the windows open*'. More specifically, it refers to the temperature at which water turns to ice, 0 °C, as in '*It will freeze tonight*'. In science, 'freezing' refers to the change of a substance from liquid to solid state, at whatever temperature that occurs.

Changes of state

'When a substance melts it turns into water.'

This is the most common misconception we encounter. Careful questioning soon showed that this arises because the concept of melting is first encountered in the context of an ice cube.

Using water to teach changes of state is fraught with problems. Not only is water anomalous (one website alone lists 73 ways in which water differs

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from other liquids: www1.lsbu.ac.uk/water/water_anomalies.html), but we also change its name as it changes state. Unlike all other substances, we do not refer to solid water (but ice) or liquid ice (but water) or water/ice gas (but steam). So children equate liquid with water, especially if the observed liquid is colourless.

What exactly is steam? Is it the gaseous form of water (which cannot be seen) or the clouds of condensed water that hang around in the air after the kettle has boiled? I've seen both definitions given in dictionaries – no wonder very young children (and the rest of us) get confused. Water is also one of the few substances that expands upon freezing. This is why ice floats (having expanded, it is now less dense than water), whereas other solids usually sink in their own liquid states.

A further complication is that, although ice starts to melt (but only slowly) as soon as it is taken from the freezer, children witness ice existing at temperatures in excess of 0 °C because room temperature is well above its melting point. They do not necessarily appreciate that heat is needed to melt an ice cube or at what temperature this happens. Most other substances need to have heat applied to make them melt, which makes more obvious the need for heat to cause this change of state.

A better approach would be to teach melting with non-anomalous substances such as butter, chocolate, wax or margarine. We use wax. Although this isn't without its problems!

'Melted wax dries up at room temperature.'

This is a problem for two reasons. As wax is a waterproof substance, it can never be said to be wet. Even when floating on water, it is repelling the water. So wax is always dry.

Drying (usually referenced from observations of ice cubes and water) involves absorption of energy to enable a change of state from liquid to gas. Solidification, on the other hand, involves the loss of energy, enabling a liquid to become a solid.

A burning candle is a great way of considering changes of state. Not only is it obvious that heat makes these changes happen but you have all three states existing side by side simultaneously (Figure 2). We have found this to be a very successful strategy for supporting development of scientific ideas.

Volume and concentration

'A full beaker of fruit juice contains more vitamins per drop than a half-empty beaker of the same juice.'

An interesting but very common misconception assumes that the volume dictates the concentration of any specific constituent. So, if making up some cordial, a set amount of the concentrate is put in the beaker and water added to taste. The sense of flavour is the same whether the concentrate came from a full bottle or a half-full one. Similarly, the final volume of liquid in the beaker has not altered the amount of cordial first added, nor has the size of the beaker used affected that.

And, at the end of the week, having that well-deserved gin and tonic, by using a large glass, we won't be drinking more gin. Unless, of course, we add more gin!

Electricity

'Batteries store electricity.'

The colloquial use of 'battery' is the foundation of another misunderstanding. The batteries we use in simple electrical experiments are more correctly called chemical cells; a battery is actually several cells joined together. 'Batteries' store energy (as chemical energy, hence chemical cell), which, as part of a complete circuit, passes into the conductor enabling the electricity to move. Electricity is usually taken to be the movement of energy (passed on from electron to electron) within the structure of the conductor.

Making simple circuits utilising solar cells in place of chemical ones is a good strategy (Figure 1).

As the circuits still work (even under some cloud cover) this proves that the electricity is not '*coming from a battery*'. In this case, energy is not being stored at all.

Figure 2 A burning candle shows solid, liquid and gas states simultaneously

'How can these solar cells work? There's no Sun today.'

Many children think that there is no Sun on a cloudy day. The fact that solar cells still work reinforces understanding that all daylight is sunlight and that it is getting through the clouds so the Sun must still be there.

This is due more to colloquial usage of there being no Sun on a cloudy day, than to an underlying misconception (akin to the Sun is moving through the sky) and the children quickly correct themselves with a bit of prompting.

'An electric circuit must contain two wires.'

Two wires … and any other assorted items! The first circuit a child builds often becomes the default in their mind. This is further complicated by the use of plastic bulb-holders, supporting boards, and so on, to enable young children with limited fine motor skills to handle the equipment. Many children then retain the idea of these accessories being a vital component for a circuit.

Children can begin to study circuits with a simple exercise: can you make a light bulb work using one bulb, one wire and one 'battery' only? Even very many adults say that this is impossible. However, children (especially younger ones) will happily try out a variety of ideas and are excited when they realise that it can be done – and that there is more than one solution. This also successfully shows that a circuit is a concept (a complete pathway for the electricity to get to each component) rather than a specific set of equipment.

'Electricity is so fast it can travel round the world by the time I've clapped my hands.'

We have met this several times (and similar comments), used to show that electricity is travelling very fast indeed. Actually it doesn't. Measurements have shown that electrons (the subatomic particles that carry the energy) move barely a few centimetres per minute. As energy passes into one end of a piece of metal, displacement causes energy to come out the other end but this is not the same energy per se. A good analogy is that of a long queue. If the person

Figure 3 Learning to describe white powders without using *'looks like'*

at the back pushes hard enough, the front person falls over. The energy has been transferred through the queue one person to the next by displacement; the person 'leaving' the queue is not the same one who joined it.

Describing substances

'Looks like is a valid description of a substance.'

Although an anonymous white substance might well look like sugar or salt (and, for safety's sake in the classroom, might well be) this doesn't help anyone who has never seen sugar or salt. This point can be further emphasised by considering all the different types of sugar (icing, Demerara, etc.) that the listener might think are being 'described', no matter what the speaker intended.

We use a variety of white substances (there are plenty in any typical kitchen) and ask the children to describe what they see (Figure 3). If they resort, for example, to saying it looks like sugar, we ask them to describe what sugar looks like, and which sugar they mean. The focus of the activity is for the children to use words such as *white, sparkly, powdery, crystalline* and *small pieces.*

This approach is also useful to emphasise that if children ever encounter an unknown white substance it could be anything and they should not assume it to be in any way safe to touch.

Commonly misused words

'Clear means colourless.'

No it doesn't! These two words are not synonymous and it is not just being pedantic to insist on the right word being used at the right time:

- **Clear means see-through or transparent;**
- **Colourless means something has no colour.**

A good method of differentiating these two terms is to use fruit juices. Several juices, such as lemon and grapefruit, are colourless but not clear; some, such as cranberry, are clear but coloured.

'Energy means power.'

Again, no it doesn't! These two words are used as if they are the same but they have very distinct meanings:

- **Energy means the ability to do work. In other words, nothing can move/work without some form of energy.**
- **Power means how well the energy is utilised. It is calculated by measuring the energy output over time.**

The more energy per second, the more powerful something is. For example, if a car is filled with petrol (a lot of stored chemical energy) but cannot go far or fast (little energy being expended in this way) then we have a car that is not very powerful.

'Mass means weight.'

No it doesn't! These are another two concepts that are used interchangeably; unfortunately, some people have resigned themselves to avoiding the distinction:

- **Mass means the amount of material comprising the object; the amount of 'stuff' something is made from.**
- **Weight means the effect gravity has upon the object; how heavy something is.**

Children seem to have no problem accepting that astronauts weigh less on the Moon than on Earth but still have the same mass, probably because they are experiencing this usage in a scientific context.

This is further complicated by the various different meanings/uses of 'weight', for example as a 'thing' that is used on a balance and as a force.

Conclusion

Misconceptions underlie the mistaken thinking not only of small children but of older students and adults. Once embedded, they are very difficult to 'unlearn'. They are relatively easy to correct and the younger the better, otherwise more advanced learning is not built on solid foundations. Misconceptions need to be corrected using concepts accessible to the learners. This means starting at the root of the problem and allowing the students to (re)discover, for themselves, usually using real, known, physical materials to support understanding and logical discussion points from direct observation. Careful observation and description are key to understanding.

Many of these problems arise because the same word is used for two different things – colloquially and scientifically. Or maybe different words are used for the same thing. Perhaps we do need to teach children how to be 'scientifically bilingual'!

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