Physics > Big idea PEM: Electricity and magnetism > Topic PEM1: Simple electric circuits

Key concept (age 11-14)
PEM1.3: Voltage

What's the big idea?

A big idea in physics is electricity and magnetism. The familiar everyday world we live in is largely a consequence of the properties and behaviour of electric charge. Matter is held together by electromagnetic forces, and these determine chemical changes. Electricity and magnetism initially seem distinct phenomena but are later found to be closely interrelated. Understanding electricity and magnetism helps us to develop our technology and find applications that can transform our everyday lives.

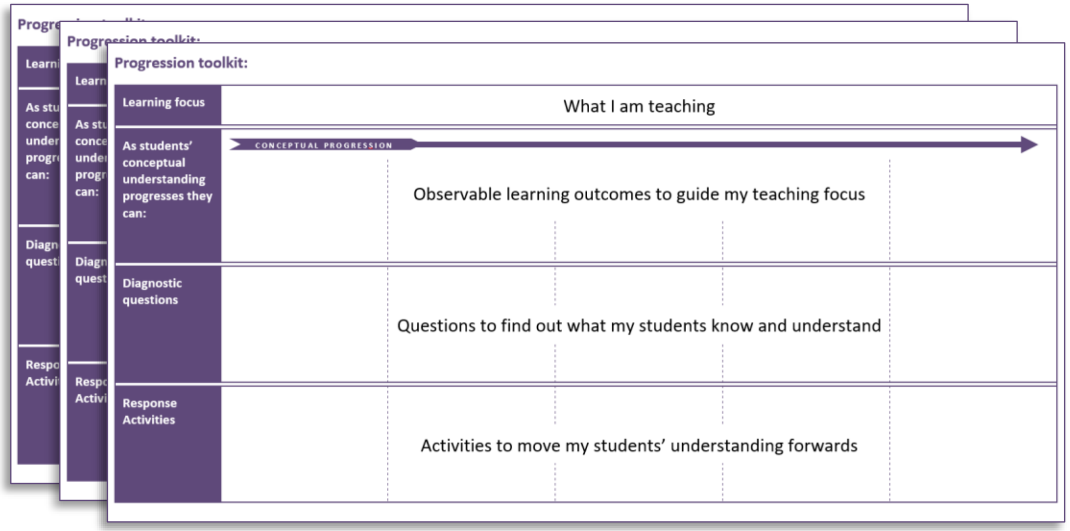
How does this key concept develop understanding of the big idea?

This key concept develops the big idea by using the concept of voltage as an *electrical push* to understand why adding batteries will increase the flow of current, and why adding resistive components will reduce the current. This approach is helpful in separating the idea of voltage from that of current.

The conceptual progression starts by checking understanding that bigger voltages make bulbs brighter. It then supports the development of the ideas that voltage is an *electrical push* that makes a current flow, and that components are made to work by the current flowing through them. This enables understanding of how a battery makes a circuit work.

How can you use the progression toolkit to support student learning?

Use diagnostic questions to identify quickly where your students are in their conceptual progression. Then decide how to best focus and sequence your teaching. Use further diagnostic questions and response activities to move student understanding forwards.



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Progression toolkit: Voltage

<table>
<tr><td>Learning focus</td><td colspan="5">The voltage, of batteries and power supplies, is a measure of their 'strength'.</td></tr>
<tr><td rowspan="2">As students' conceptual understanding progresses they can:</td><td colspan="5">CONCEPTUAL PROGRESSION</td></tr>
<tr><td>Describe the effect of different battery voltages on simple circuits.
P</td><td>Describe the voltage of a battery, measured with a voltmeter, as the strength with which the battery can 'push' current around a circuit.</td><td>Use the idea of an 'electrical push' to explain the effect of different battery voltages on a circuit.</td><td>Apply the idea of an 'electrical push' to predict the effect of different series combinations of 1.5V batteries on simple circuits.</td><td>Calculate the total voltage of combinations of different batteries in series.</td></tr>
<tr><td>Diagnostic questions</td><td>Which is brightest?</td><td colspan="2">Current or voltage?</td><td>Combining 1.5V batteries</td><td>Two different batteries</td></tr>
<tr><td rowspan="2">Response activities</td><td colspan="5">String loop model (voltage)</td></tr>
<tr><td></td><td></td><td>Adding batteries (1)</td><td colspan="2">Adding batteries (2)</td></tr>
</table>

Key:

P Prior understanding from earlier stages of learning

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Progression toolkit: Voltage

Learning focus	Voltage is needed to push current through a component, and a particular voltage pushes just the right amount of current through a component for it to work well.				
As students' conceptual understanding progresses they can:	CONCEPTUAL PROGRESSION → Describe the effect of too little, or too much, voltage across a component. **P**	Describe the voltage across a component as the strength of 'push' being used to get current through the component.	Use the idea of an 'electrical push' to explain why different components (usually) work best at a particular voltage.	Use the ideas of 'electrical push' and resistance to explain why adding components to a series circuit changes the current.	Calculate the total voltage needed to push the 'right amount' of current through a combination of several components. **B**
Diagnostic questions	Bulb markings			Adding components	A battery that works
Response activities	Bigger voltage			String loop model (voltage)	

Key:

P Prior understanding from earlier stages of learning

B Bridge to later stages of learning

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Progression toolkit: Voltage

Learning focus	In an electric circuit energy is shifted from the chemical store of a battery to the moving charge, and from the moving charge to circuit components.				
As students' conceptual understanding progresses they can:	CONCEPTUAL PROGRESSION → Recognise that batteries are full of chemicals that are changed to make a circuit work.	Explain why bigger batteries last longer than smaller ones, of the same type and voltage, using the idea of a 'chemical store' of energy.	Describe the shift of energy from the chemical store of the battery to the moving charge (current); and from the moving charge to circuit components.	Describe how we know brighter bulbs shift energy from the chemical store of a battery at a faster rate.	Use understanding of batteries and voltage to justify battery choice and limitations in real-life situations. **B**
Diagnostic questions	1.5V batteries		How a battery works	Battery life	Electric car
Response activities	String loop model (Voltage)				

Key:

B Bridge to later stages of learning

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What's the science story?

The battery (or power supply) pushes current around an electric circuit. The voltage of a battery is a measure of its 'strength'. Its size depends on the chemicals used to make the battery. It is measured in volts (V).

If the battery in a simple circuit is replaced by a (physically) larger battery with the *same* voltage, the effects are the same, but the battery lasts longer. It has a larger chemical store from which it can shift energy to the moving electrical charge.

If the battery in a simple circuit is replaced by one with a larger voltage, the effects observed are larger, for example motors run faster. This is because the battery gives a bigger electrical push which makes the current larger.

If several batteries are connected in line (in series), the voltage of the combination is the sum of the voltages of the individual batteries, taking account of their directions.

Many devices are designed to be used with a battery (or power supply) that has a particular voltage; often this is marked on the device. If a device is connected to a battery of smaller voltage, it will either operate more weakly or not at all. A device can be damaged if it is connected to a battery whose voltage is higher than it is designed for (because it causes a current that is larger than the device is designed to take).

In an electric circuit energy is shifted from the chemical store of the battery to the moving charge, and from the moving charge to circuit components. For example, when a bulb is connected to the battery, the battery's chemical store of energy drops as it shifts energy to the moving charge. At the same time the bulb warms up, as energy is being shifted to it by electrical working (as the current passes through the resistance of the filament).

What does the research say?

Many researchers such as Driver *et al* (1994), Gott (1984) and Shipstone (1985) have found that students' explanations, at an early stage, are likely to use the words current, voltage, electricity and energy to mean the same thing. To advance their understanding of electric circuits it is necessary for students to distinguish between: the current flowing through the circuit (that is conserved); the energy that is stored in the battery and then transferred elsewhere; and the voltage.

When talking about voltage, Driver *et al* (1994) recommend using the term *voltage* instead of *potential difference* to avoid unnecessary confusion with terminology. Even though *potential difference* has now been introduced into the English National Curriculum at Key Stage 3, students are already very familiar with the term *voltage*, and using this instead of potential difference does not detract from their understanding.

Driver et al (1994) suggest that to develop a good understanding of voltage, it is better, at this stage, to describe it as a measure of the strength of a battery's 'push'. In one study of 14-15 year old students in England, it was found that that 31% thought of voltage as something that flowed around a

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circuit (Shipstone, 1985). By describing a bigger voltage as a bigger push, it is relatively straight forward to use a model to demonstrate the relationship between current and voltage, and to explain how changes to one part of a circuit affects every other part.

Models are very useful to explain things we cannot see and there are many models for an electric circuit. Research shows that a mechanical model such as a string loop is best, because it helps students to recognise how all points in a circuit influence all others (Driver et al, 1994). Other types of models, often included in text books, have been shown to be much less effective with students.

To understand how a battery works in a circuit it is helpful to think of it as a chemical store (Millar, 2011). The chemicals in it are changed as they shift energy to the moving charge in a circuit. Batteries with bigger voltages shift energy more quickly because they are pushing the electric charges harder. Most 11-14 year old students do not think of a battery in this way (Driver *et al*, 1994). In one study (Maichle, 1981) 340 out of 400 secondary school students in Germany thought of a battery as 'storing a certain amount of electricity' that was ready to flow round a circuit.

The first progression toolkit for voltage focuses on the suggestion of Driver *et al* (1994) to describe voltage as a measure of strength of a battery's push. Some students may need reminding of the effects of a bigger voltage on a bulb, or a motor etc. When they can describe the effects of different voltages, they can be introduced to the idea of voltage 'as the strength of a battery's push' and use this definition to distinguish voltage from current. Adding batteries to a circuit gives students the opportunity to consider how each additional battery affects the current. Discussion about a string loop model can be used to support students' understanding and allow them to test out their ideas on voltage.

The second progression toolkit for voltage engages students in thinking about the effect of the strength of a battery's push on the current, whilst taking into account other components in the circuit. Observing the effect of putting voltages across a bulb, which are lower or higher than the bulb's marked value, gives students the opportunity to develop their explanations for how a battery pushes current through a bulb, and how the bulb resists it. Applying this understanding to some different circuits, students can rehearse and consolidate their thinking (Gott, 1984).

The final progression toolkit for voltage uses Millar's description of how we can think about energy in an electric circuit (Millar, 2011), to explain how batteries make circuits work. Students may first need introducing to the concept that a battery is a 'chemical store' of energy, and then discussions around the string loop model can be used to develop descriptions of how energy is transferred from the chemical store to the components, by way of the moving charge. When students have an understanding of this, they can apply their thinking to real life situations.

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Guidance notes

As explained above 'voltage' has been used to mean 'potential difference' to avoid unnecessary confusion. The terminology of 'potential difference' is best introduced to students when they have a clear understanding of voltage.

'Battery' has been used throughout and not 'cell'. Strictly speaking a 4.5V battery is made up from three 1.5V cells; a cell being the unit that produces or stores electricity – such as a standard 1.5V battery. Switching between 'battery' and 'cell' can be somewhat confusing, contradicts everyday use of the word 'battery', and is not necessary to develop understanding.

This is a good point at which to introduce students to the use of the voltmeter. Technically, it is more correct to quote voltage as the voltage '*across'* a component and not the voltage '*of'* the component. This is because the voltage across a component, even a battery, is not fixed, but changes when the circuit it is connected to changes. For example, the voltage across a commonly used battery is roughly 1.5V when it is not connected to anything, but goes down to about 1.4V when it is connected in a simple circuit. This is because when a current flows, some of the 'push' (voltage) is needed to move the current through the resistance of the battery – in use batteries will warm up a little because of this.

Voltage can be defined in two ways: the voltage across a battery is the energy it transfers to each Coulomb of charge passing through it; and the voltage across a component is the energy transferred from each Coulomb of charge passing through it to the component. (A Coulomb is the charge on a fixed number of electrons.) In the progression toolkits these definitions have been written for voltage in terms of an 'electrical push'.

The latter of these definitions in the progression toolkit is: *voltage across a component is the strength of 'push' being used to get current through the component.* This invokes a clear understanding that effort is needed to push current through a component, and the bigger the voltage across the component, the bigger the effort applied to push current through it. This is not a perfect definition, but a very useful one at this stage of students' understanding because it encourages the correct linking of the ideas of voltage and current. (The definition breaks down in situations where no current can flow, such as a gap in the circuit.)

Batteries introduce the concept of *energy* into electric circuits. In BEST resources we are following the model of energy stores and pathways that is supported by the Institute of Physics (supportingphysicsteaching.net, 2018). This way of thinking has informed the way that energy has been described in the 2013 version of the English National Curriculum, as well as in some exam board's 2018 versions of science GCSE specifications for England.

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Website

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