Many analogies are used to introduce the concepts of circuits, from water pipes to pizza delivery. But how helpful are they?

There are some fundamental circuit ideas you’d want students to understand by the age of 14. From primary school, they should know something flows and that a circuit needs to be complete for this to happen. Next they need the ideas of charge (what’s flowing), current (rate of flow), potential difference (cause of flow) and resistance (opposition to flow).

Teachers are often tempted to introduce a range of models and ask their students to analyse the strengths and limits of each. But without a secure understanding of the underlying principles of circuits above, you risk breaking the fragile schema which they’ve tentatively been building. Instead, focus your teaching on how electricity works and stick to one model. The Rope Loop (Activity 1) is a good one – it isn’t a silver bullet, but it is simple and hands on.

When your students are building circuits, rather than spending time assembling one then dissembling it to build a new one, try using the Continual Conversion approach (Activity 2). It is a neat approach and takes away a layer of trauma – for both students and teacher.

Don’t let your students get their wires crossed

- Research shows students often use the terms current, voltage, electricity, power and energy interchangeably when explaining what happens in an electric circuit.
- A simple circuit questionnaire can uncover where students are starting from - and how much they can retrieve later. This is a revealing exercise at all Key Stages – even for post-16 students.
- Younger students may think that the battery (the ‘source’) gives something to the bulb (the ‘consumer’) so a single wire from a battery terminal to a bulb terminal will be enough to light the bulb. Show them there is more than one wire and it’s actually a loop. Also, show them what the stripped bare copper looks like inside the insulation.
- Be careful with everyday language. Referring to a ‘power’ pack to supply a voltage could cause confusion. Moving your hand around a circuit diagram to mimic the current could be reinforcing the idea of something being dropped off in sequence, with the first bulb being brighter than the next.
- Teach series and parallel circuits separately. Focus first on a secure understanding of current in a series circuit using the Rope Loop model (see Activity 1) and practice connecting an ammeter correctly. This will address the ‘consumer’ model, outlined above, by showing that the current is the same all the way around the circuit and through each component.
- When talking about energy, introduce the idea of the circuit transferring energy from the battery to the surroundings. The current raises the temperature of the bulb’s filament (by electrical working); and the hot filament transfers energy to the surroundings by heating. Now you can begin to make qualitative observations based on bulb brightness.
- Driver et al (1994) suggest describing voltage as the strength of the ‘push of the battery’ and ensuring the distinction between current and voltage is embedded at this stage. Keep the definition of voltage as per unit charge until later, when you introduce equations and calculations.

Tip: invest in LED bulbs as these have a more reliable brightness than traditional filament bulb so brightness comparisons within a circuit are much more straightforward.

The tabletop rope loop model is great for younger students bit.ly/tabletoploop

Thanks to Gethyn Jones, director of physics at Harris City Academy Crystal for continual conversion approach. bit.ly/CPcircuits
Activity 1: Rope loop model

This activity introduces students to simple electrical circuits using a mechanical analogue. Although some teachers do it with 10-20 students holding onto a rope at different points, it works better with just one or two volunteers. Too many hands leads to gripping the rope too tightly or pulling too hard and you’ll end up battling to get the rope – and your students – to do what you want!

Equipment

- A length of rope approx 3m – ideally made of nylon and speckled
- Duct tape (optional)

Preparation and health and safety

Tie the rope into a loop. If you are using a nylon rope, melt or glue the ends together then cover the join with duct tape. Avoid rope burns by making sure students don’t grip the rope too tightly.

Procedure

Ask for one student volunteer. They represent the light bulb in a circuit. Get them to grip the rope lightly with one hand so rope can slip through easily. You, the teacher, are the battery and, as such, you provide the voltage. Do this by making the rope circulate, pulling it at a steady rate, hand over hand. The rate of flow of the rope is the current. Ask your students to think about:

- Where did the current start flowing first?
- How does the current in and out of the bulb/battery compare?
- What is happening to the ‘light bulb’s’ hand?

Model Circuit

The rate of flow of rope into and out of your hand and those of the volunteer’s is the same.

The speckles are already there in the loop, they start moving at once and at the same speed everywhere around the loop.

As the rope moves, the temperature of the volunteer’s hand will rise and raise the temperature of the surroundings. The energy stored chemically by the ‘battery’ has decreased and the energy stored thermally by the surroundings has increased.

Energy is being transferred by the whole system working mechanically. It should be clear that there is no way that one side of the rope is ‘carrying energy’ from the source to the volunteer’s hands.

Extension ideas

1. Model a series circuit by adding a second bulb-volunteer next to the first. The flow decreases because there is more resistance in the circuit.

2. Model a parallel circuit by adding a second, shorter rope loop to the system with its own bulb-volunteer. You, the battery, hold both ropes in your hand, providing the same voltage to both loops. Where the ropes overlap in your hand, the speed of the flow is exactly the same as before so the current in the original loop is unchanged. But there are now more electrons flowing – and you, the battery, will tire more quickly.

3. Model alternating current, by constantly changing the direction of motion of the rope. The temperature of the bulb quickly rises and, over time, the circuit transfers energy to the surroundings by heating. However, and importantly, no ‘electrons’ have travelled from the AC source to the bulb.

The rope should lie lightly in the upturned palm of the ‘light bulb’, rather than being gripped palm down. This will also enable you to see what your volunteer is up to!

spark.iop.org/rope-loop-teaching-model
Activity 2: Circuits using continual conversion

This approach to investigating circuits avoids students assembling and dissembling circuits, helping them see the similarities and differences between different set-ups. It also makes brightness comparisons simple. Run the series activity first then, in a later lesson, do the parallel circuits activity. Student instruction sheets and circuit diagrams are printed on page 12.

Circuit A: series

Equipment
Each group of students will need:
• Electrical cell (or other power supply)
• 3 identical bulbs
• 2 ammeters
• 8 leads
• Copies of either Circuit A or Circuit B student instructions sheet (overleaf)

Procedure
Before the lesson, set up the circuit and leave it at the side of the lab. Ask students to follow the instructions on their activity sheet – they can look at your set up if they get stuck. In both scenarios, students should note the identical readings on both ammeters to demonstrate the idea that current is conserved.

Short-circuiting the bulbs in series
In circuit A, at the start of the activity, the students use leads Y & Z to bypass two of the bulbs. Ensure they do not short circuit all the bulbs: there must be at least one bulb in the circuit to avoid the current becoming too high and damaging the ammeter.

Circuit B: parallel

Circuits tips

Get on track with a Tube map
Most circuit diagrams don’t look like the jumble of wires they represent. This can be confusing for younger students. To help them make the connection, compare a geographically accurate London underground map (bit.ly/CPgeotube) to the famous schematic version. There is a lovely transformation between the two at bit.ly/CPtubemap

Turn thinking around by moving the battery
Most circuit diagrams are drawn with the battery at the top and the components underneath. If your students only see this arrangement, they may struggle when faced with a circuit drawn ‘on its side’. Introduce different circuit diagrams early – it will also help them get used to phrases like “voltage drop” at all angles.

Realise potential by colouring it in
Voltage is difficult to visualise. Colouring in the connecting wires helps students see potential drops across light bulbs and power supplies. See Potential difference in colour at bit.ly/PEdReeves03 for more detailed instructions (bear in mind colour blindness issues when choosing colours for this activity. Advice at bit.ly/1OPcolourblind)
Activity 2: Student instructions

Circuit A: bulbs in series

In this activity you will predict, observe and explain what happens in circuits with a single loop.

1. Set up the circuit shown on the right. Connect leads around two of the bulbs to 'short circuit' them. To start, only one bulb should be lit. Record the readings on both ammeters.

2. Predict what will happen if you disconnect lead Y: will the ammeter readings stay the same, increase or decrease? Disconnect lead Y. What happens to the readings?
   Write your own explanation about why the readings changed.

3. Predict what will happen if you also disconnect lead Z. Disconnect lead Z. Record your observations and write an explanation.

4. Predict what will happen when you reconnect lead Y. Connect lead Y. Record your observations and write an explanation.

Circuit B: bulbs in parallel

In this activity you will predict, observe and explain what happens in circuits with more than one loop.

1. Build the circuit shown on the right. To start, only one bulb should light up. Record the readings on both ammeters.

2. Predict what will happen if you connect lead Y: will the ammeter readings stay the same, increase or decrease?
   Connect lead Y. What happens to the readings?
   Write your own explanation about why the readings changed.

3. Predict what will happen if you also connect lead Z. Now connect lead Z. Record your observations and write an explanation.

4. Disconnect the two leads. Repeat step 2 but this time for lead Z.