Electricity and Magnetism: Teaching and Learning Issues 03

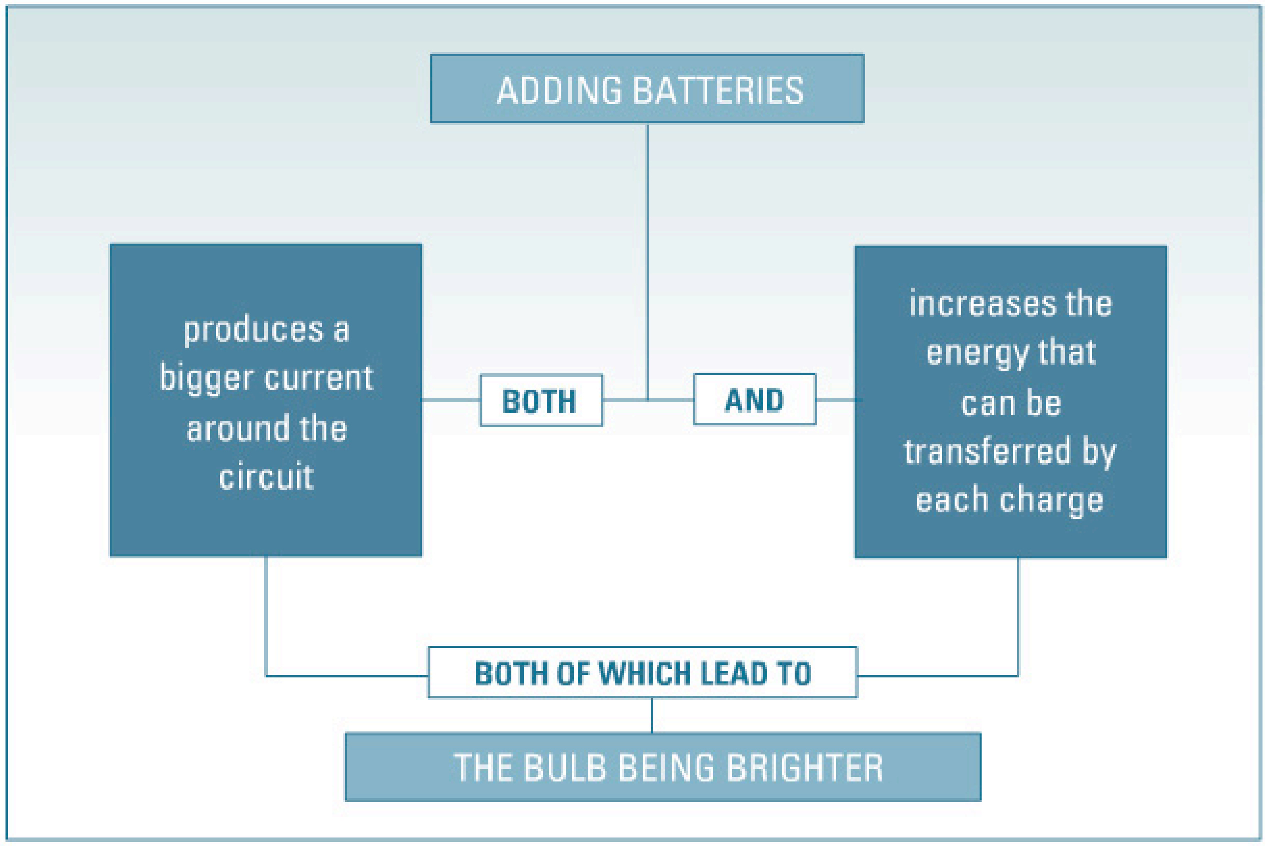
Contents

This is the 'Teaching and Learning Issues' that explains the particular challenges. To develop your expertise in the episode, work with the 'Physics Narrative' and the 'Teaching Approaches'. Navigate to any part of the topic using the Topic Menu, or use the tabs below to stay within this episode. .

Challenges as you add more batteries

The fact that adding a second battery in series results in the bulb being brighter makes intuitive good sense to most pupils. Pupils reason that the double source (or battery) is now supplying just one consumer (or bulb) and therefore gives a bigger effect.

A more detailed explanation is, however, more demanding for pupils and is based on two effects which occur simultaneously:



With an extra battery, the positive terminal of the battery becomes more positively charged and the negative plate becomes more negatively charged, and this exerts a bigger force on the charges. As a result:

- More charges pass through the filament each second.
- Each charge shifts more energy.

In other words, adding a battery both increases the current and increases the energy that is shifted by each charge passing.

Challenges as you add more batteries

- Challenge 1: Adding batteries produces a bigger current
- Challenge 2: Adding batteries supplies more energy
- Challenge 3: Putting the two lines of thinking together

These challenges reflect research carried out into alternative conceptions.

Challenge 1: Adding batteries produces a bigger current

Wrong track: More current flows out of the extra battery.

Right lines: Extra batteries provide a bigger push on all of the charges in the circuit. When a second battery is added to the circuit, the positive side of the combined battery becomes more positive with respect to the negative side. A bigger force is therefore exerted on all of the charges in the circuit, as they are pushed away from one side of the battery and attracted towards the other.

Adding a battery, therefore, results in the same charges (in battery, bulb and connecting wires) moving around the circuit at a greater rate. More charges pass each point per second. In other words, the current increases.

Challenge 1: Adding batteries produces a bigger current

This incorrect line of reasoning goes back to the idea that the battery is the source of the charges which make up the electric current.

Thinking about the teaching

The points that needs to be emphasised here are that:

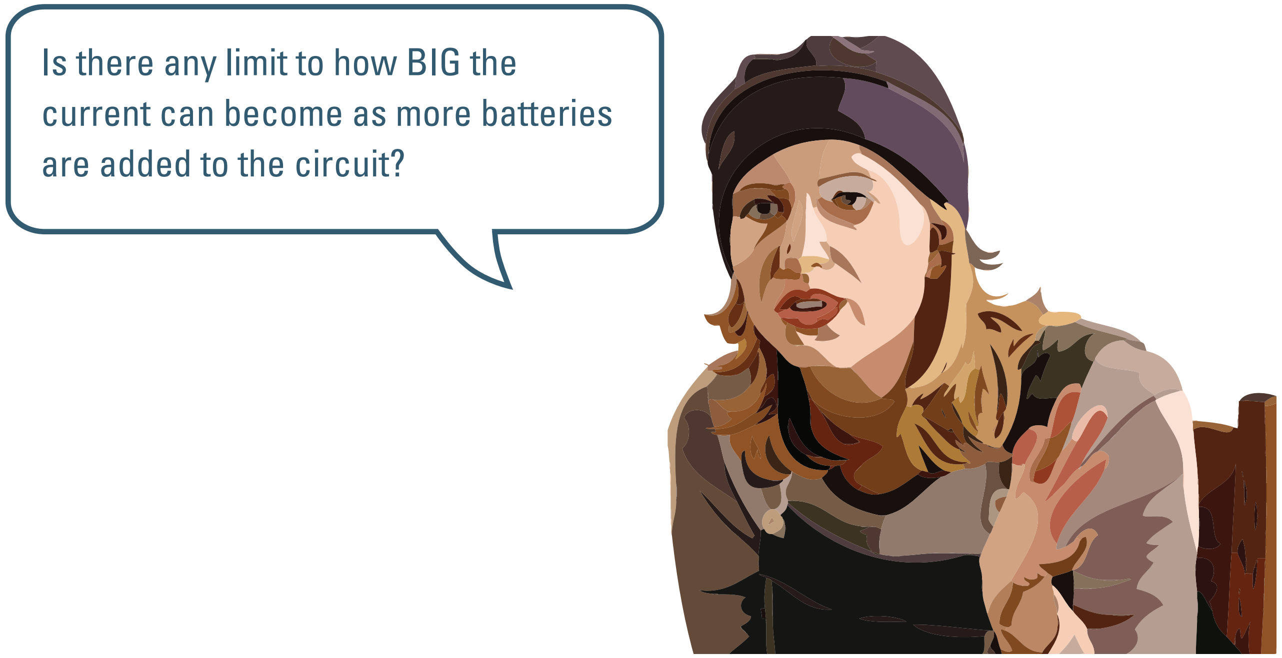
The charges don't come from the battery. They start off in the battery, connecting wires and bulb. The bigger current is due to those charges moving around more quickly.

Expressed in terms of the rope loop:

It's like with the rope loop. The rope didn't come from me in the first place. The loop is already there and, as when a second battery is added, I simply moved the same loop around more quickly.

How BIG can the current get?

Good teaching questions that challenge pupils' understanding and encourage discussion can often be generated by considering extreme cases. So:



In theory, as more batteries are added the charges in the circuit are simply pushed round more quickly, so the size of the electric current increases. In practice, there is a limit to the size of electric current through the bulb - the filament melts.

The supermarket picture teaching analogy

As the teaching develops and you progress with ideas relating to the electric circuit model, you may wish to introduce a second teaching analogy. The supermarket picture offers a different way of visualising the electric circuit, compared to the rope loop. Whilst the rope loop directs attention to the way in which the push of the battery sets the charges in motion, the supermarket picture focuses explicitly on the energy shifted in the circuit.

Electric circuit model

The battery maintains the motion of the charges around the circuit. As the charges pass through the bulb, energy is shifted to the stores of the surroundings.

Teaching analogy: Supermarket picture

A bakery provides bread, which delivery vans transport around a circuit to the local supermarket where it is sold or “dissipated”.

The supermarket picture teaching analogy

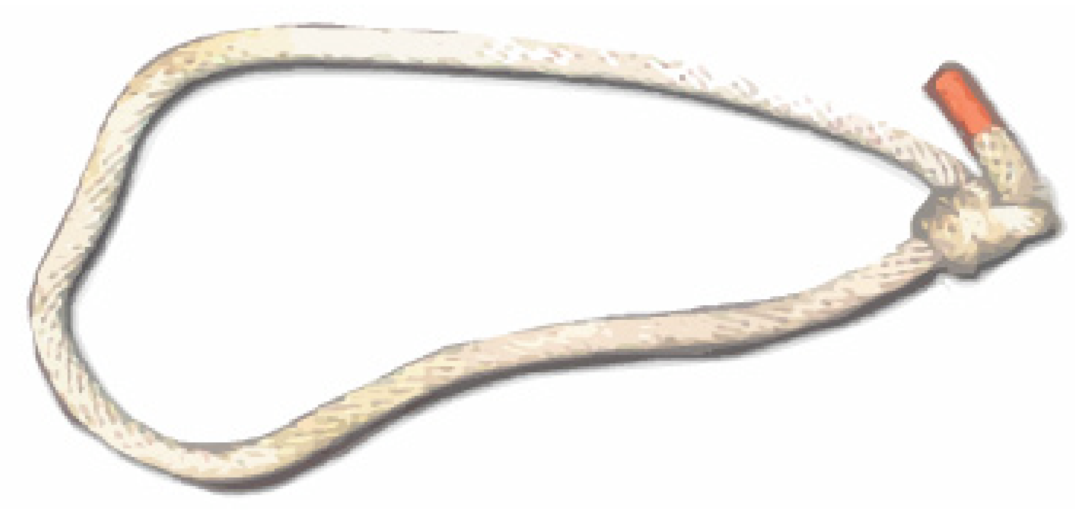
The idea here is that in the electric circuit, there is an overall transfer of energy from battery via bulb to surroundings, which is made possible by the flow of charge. In the supermarket picture teaching analogy, there is an overall transfer of bread from bakery via supermarket to customers, which is made possible by a continuous loop of vans. The supermarket picture and rope loop teaching analogies have different, but we think complementary, strengths:

Supermarket picture

Focuses on the charge/energy story, helping pupils to distinguish between charge or current (vans) and energy (bread).

Rope loop analogy

Focuses on the current/resistance/electrical working story, helping pupils to understand the relationship between the “push” of the battery (from the teacher), the current (the movement of the rope) and the resistance in the circuit (pupils gripping the rope), and how this shifts energy from the teacher to the pupils.



The supermarket picture teaching analogy

Introducing the supermarket picture provides an excellent opportunity for reviewing and consolidating some of the basic features of the electric circuit model previously introduced:

Now it's obvious that the vans don't all start off inside the bakery. They're out there on the road and the bakery manager sets them moving around. In just the same way, the charges don't come from the battery. The battery just makes them move round the circuit. (See episode 1, challenge 1.)

Look everybody! As soon as one van moves, they all move. In just the same way, as soon as the circuit is completed, the charges start moving in all parts of the circuit. (See episode 1, challenge 2.)

The same number of vans returns to the bakery as leaves it. The vans don't get used up, or disappear, on the way around. In just the same way, the current doesn't get used up on the way around the circuit. (See episode 2, challenge 3.)

Challenge 2: Adding batteries supplies more energy

Thinking about the learning

The idea that adding batteries increases the rate at which energy is supplied to the circuit makes intuitive good sense to most pupils.

Thinking about the teaching

Both the rope loop and supermarket picture teaching analogies are likely to be useful here in helping the pupils to picture what is going on.

Choose the analogy carefully, to deal with the anticipated difficulties. Remember the earlier advice to make consistent use of a single analogy, if you think it possible. The advantage is that pupils are more likley to build up a model to think with, in which they can have confidence, as it provides them witha reliable and tested guide, applied ot many situations.

So, with the rope loop, I worked harder to pull the rope around with a bigger force. I seem to remember that Anita felt the benefit of my efforts as her hand warmed up. It's a good job I didn't have to keep going for too long!

Think about the supermarket picture! When an extra bakery is added, each van collects twice the load of bread. It's just the same with the electric circuit. When an extra cell is added, twice the amount of energy is transferred to each charge.

Challenge 3: Putting the two lines of thinking together

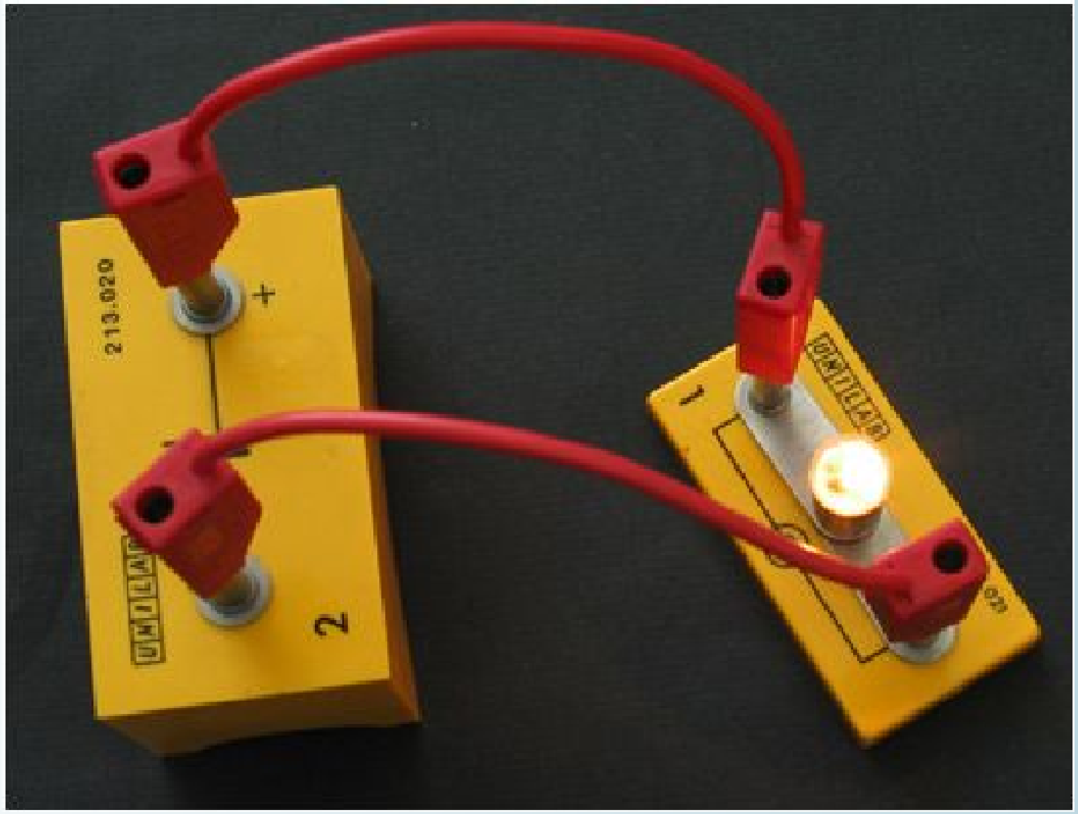
Thinking about the learning

The challenge for the pupils here is to recognise the two effects which follow from increasing the number of batteries and lead to the increased brightness of the bulb:

- The bulb is brighter because the current is bigger - more charges per second.
- The bulb is brighter because the extra battery shifts more energy for each charge.

Imagined steps in an argument

Here you think about what affects the energy transferred by a cell.



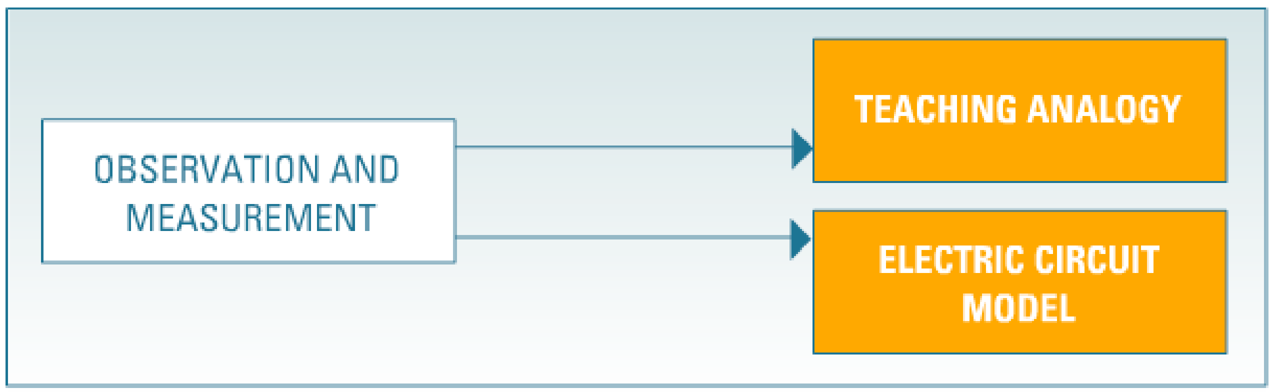
STEP 1 of 5

Challenge 3: Putting the two lines of thinking together

Thinking about the teaching

We return to thinking about how to draw on the three key elements in sequencing this part of the teaching.

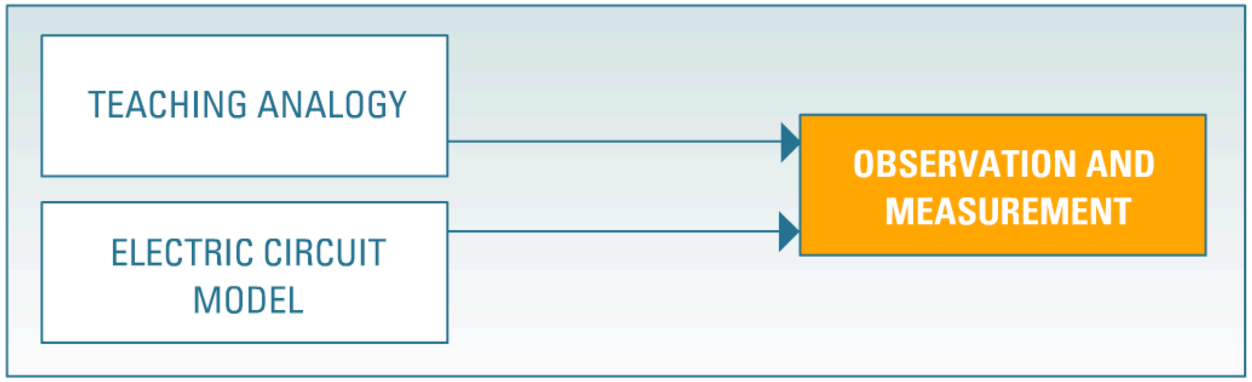
Here our advice is to start with observation/measurement (see what actually happens) and then account for these observations and measurements in terms of the electric circuit model and a teaching analogy.



Challenge 3: Putting the two lines of thinking together

This approach is the reverse of that taken in episode 2, where the teaching started with making predictions from the model/analogy.

With the approach taken here, less demand is placed on the teaching analogy.



OK, so what can you tell me about the current when a second battery was added?

Right, the current was BIGGER and the bulb was brighter.

Now, can anybody picture what's going on here in terms of the bakery and supermarket?

That's exactly right! We can imagine that with the second bakery each van is loaded with twice the amount of bread and the vans move around more quickly. It was the same with the rope. I pulled the rope around more quickly and Julia felt her hands being heated up more.

Now who can talk through that in terms of charges and energy?

Excellent! As the second battery is added, the charges move around the circuit more quickly and twice as much energy is transferred by each charge.

Strengths and weaknesses of the supermarket picture teaching analogy

All teaching analogies have their strengths and weaknesses and it is important to be aware of what these are.

Strengths

A clear strength of the supermarket picture teaching analogy (and all of the other similar analogies of its kind) is the way in which it distinguishes between energy and current. The point has been made that pupils can easily mix up current and energy, so the teaching analogy directly addresses this problem.

Weaknesses

A weakness of the supermarket picture teaching analogy is that it paints the picture of charges "collecting" energy only in the battery and "giving out" energy in the bulb. As has been detailed, this is not the case. The charges gain energy as they are set into motion in the electric field created by the battery all around the circuit. However, it is certainly arguable that the circuit behaves as if the charges gain energy in the battery since the battery is the ultimate source of energy for the circuit.

A further possible weakness of the supermarket picture is its reliance on ad-hoc rules. For example in moving from one to two bakeries (adding a battery), it is reasonable to suggest that each van collects twice the amount of bread, but it is not so clear as to why the vans also move round at twice the rate. For the correct working of the analogy it is essential to recognise that changes to the amount of bread carried per van and the rate at which the vans move round cannot occur independently. Similarly, in adding an extra supermarket it is necessary to accept that the bread is shared between the supermarkets and that the loop of vans is slowed down.

Nevertheless, and bearing these strengths and weaknesses in mind, we believe that the supermarket picture can provide an accessible starting point for many pupils and teachers to think and talk about electric circuits.

Challenges as you add more lamps

The fact that adding a second identical bulb in series results in the two bulbs being dimmer makes intuitive good sense to most pupils. Their underlying reasoning is that the single source (or battery) is now being shared between the two bulbs.

- Challenge 4: Adding a bulb reduces the current
- Challenge 5: The resistance sets the current for the whole circuit
- Challenge 6: The energy is shared equally between the two bulbs
- Challenge 7: Putting together thinking about two lamps

These challenges reflect research carried out into alternative conceptions.

Challenge 4: Adding a bulb reduces the current

Thinking about the learning

The key idea for the pupils to get hold of here is that adding an extra bulb introduces more resistance to the circuit, and this has the effect of slowing down the passage of charge around the whole circuit. The number of charges passing any point in the circuit is reduced; in other words, the current is reduced.

Thinking about the teaching

The rope loop teaching analogy is very useful in getting over the idea that the electric current goes down when a second bulb is added to the circuit.

OK! Now I want both Julia and Anita to loosely hold the rope. I'm pulling the rope round with the same force and it's obvious that Anita's extra grip or resistance has slowed down the whole of the rope loop.

Having talked through the teaching analogy, attention is returned to the electric circuit model:

When a second bulb is added, extra resistance is introduced to the circuit. This has the effect of slowing down the flow of charges all around the circuit. In other words, the current is reduced.

Challenge 4: Adding a bulb reduces the current

Why does adding bulbs add resistance?

It is worth emphasising the point here that it is the filament of the bulb that offers the resistance to the flow of current:

The filament of the bulb is made from very thin tungsten wire. The filament is designed so that it is difficult for the charges to pass through and, as they do, they collide with the tungsten atoms and the whole lot heats up until the filament glows white-hot. This is rather different from what happens in the connecting leads. These are made from relatively thick lengths of copper wire that have a very low resistance and so very little heating occurs in the connecting leads.

Challenge 5: The resistance sets the current for the whole circuit

Right lines: The extra resistance at a single place in the circuit has the effect of reducing the current around the whole circuit. The same amount of charge passes per second through each and every part of the circuit.

Wrong track: The current is smaller in the filament of the bulb because of the very high resistance, but then speeds up and gets bigger through the conducting wires.

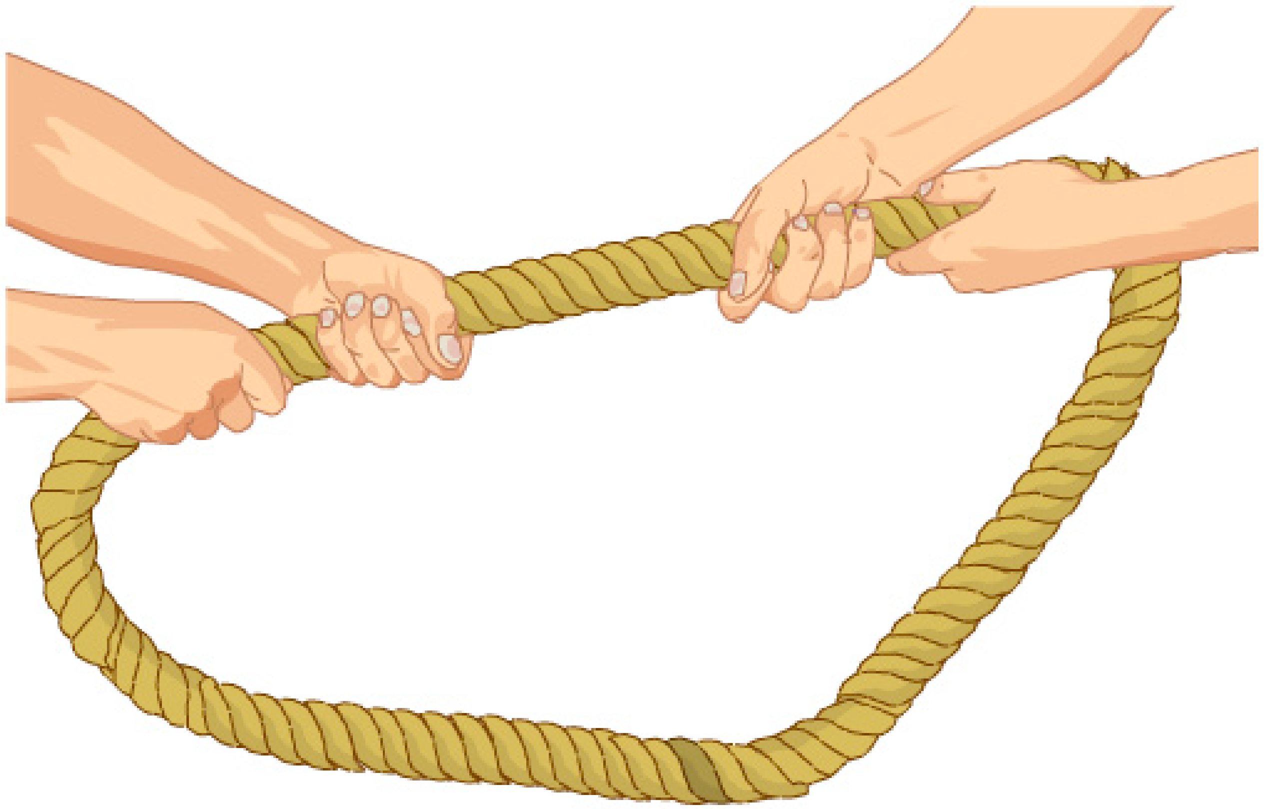
Challenge 5: The resistance sets the current for the whole circuit

Thinking about the learning

A further important point to emphasise is that when additional resistance is introduced to a circuit in one place, the current is reduced around the whole circuit. This can be the source of confusion for pupils.

Thinking about the teaching

It may be helpful to think of the resistance as providing the rate-determining step for the whole circuit. The rope loop is useful in getting this point across. As further resistance (pupils holding the rope) is added to the circuit, the movement of the whole rope loop is slowed down. All parts of the rope loop move around at the same speed.



Challenge 5: The resistance sets the current for the whole circuit

How SMALL or BIG can the current get?

It is worth exploring the effect on the current of a full range of resistance.

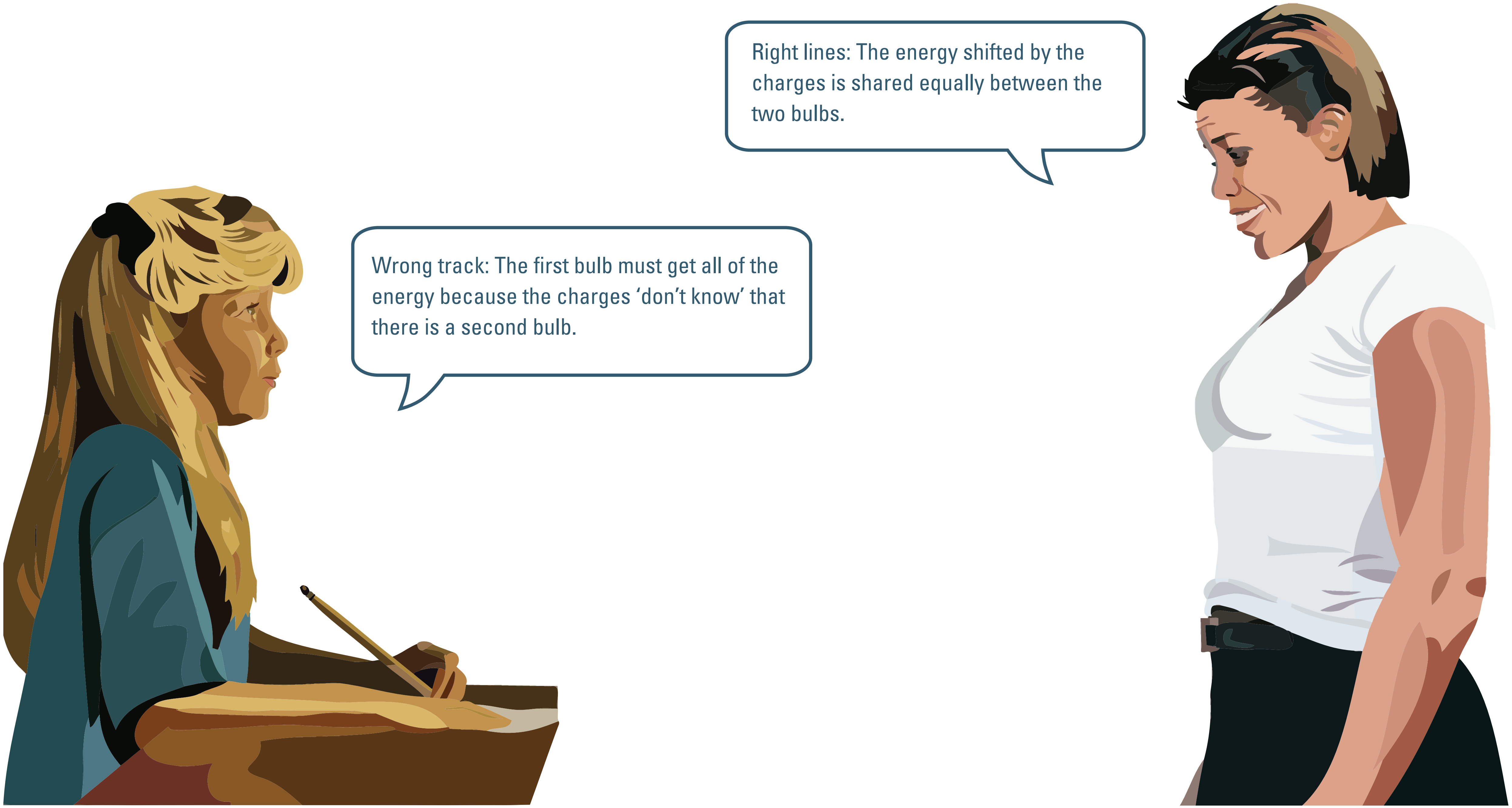
What would happen to the current if more and more bulbs were added to the circuit?

What would happen to the current if all of the bulbs were removed from the circuit and we were left with a connecting lead from one side of the battery to the other?

Quite simply, as more bulbs are added, the resistance in the circuit increases, the charges move around more slowly and the current gets smaller. With an infinite resistance, the current would fall to zero. We can demonstrate this simply by making a gap in the circuit.

This is called a short circuit and is to be avoided! Because there is very little resistance in the circuit (apart from that provided by the battery itself), a very large current results with the charges moving around very quickly. It is likely that the battery will be damaged, or the wire becomes so hot that it will burn you or even melt!

Challenge 6: The energy is shared equally between the two bulbs



Challenge 6: The energy is shared equally between the two bulbs

The idea to get over here is that there is a maximum amount of energy which the battery can shift as each charge passes and that this energy is shifted wherever there is resistance in the circuit. If there are two places of equal resistance, then the energy is shared equally between those two places.

For each charge passing:

- Half of the energy is shifted by the first bulb.
- The remainder of the energy is shifted by the second bulb.

Thinking about the learning

Problems can arise for those pupils who think of the charges as starting out from the battery and transferring all of their energy in the first bulb. For this reason it is helpful not to talk as if the battery hands over something to the charges, which they carry round to the bulbs. This may well support the idea that the charges cannot play an active part in the shifting of the energy until after they have passed through the battery. This is not true.

Thinking about the teaching

Once again, the rope loop can be very helpful in talking through the idea that with two bulbs there is a simultaneous and equal transfer of energy at the two sites.

Challenge 7: Putting together thinking about two lamps

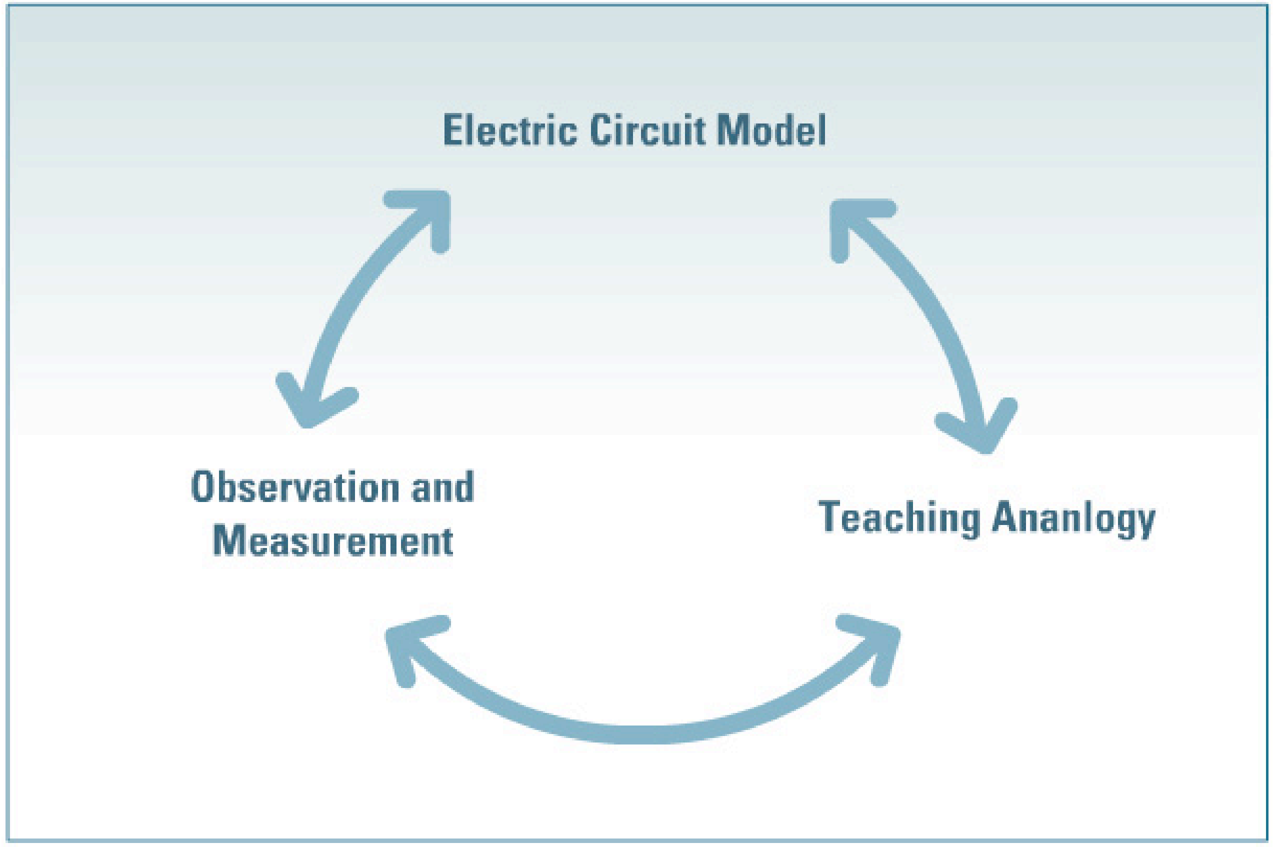
Thinking about the learning

The challenge for the pupils here is to be able to provide a full explanation as to why the two bulbs become equally dim:

The bulbs are now dimmer because adding the extra bulb increases the resistance and reduces the current in every component of the whole circuit. As a result, fewer charges pass per second through each bulb, and each charge shifts less energy as it passes through each filament.

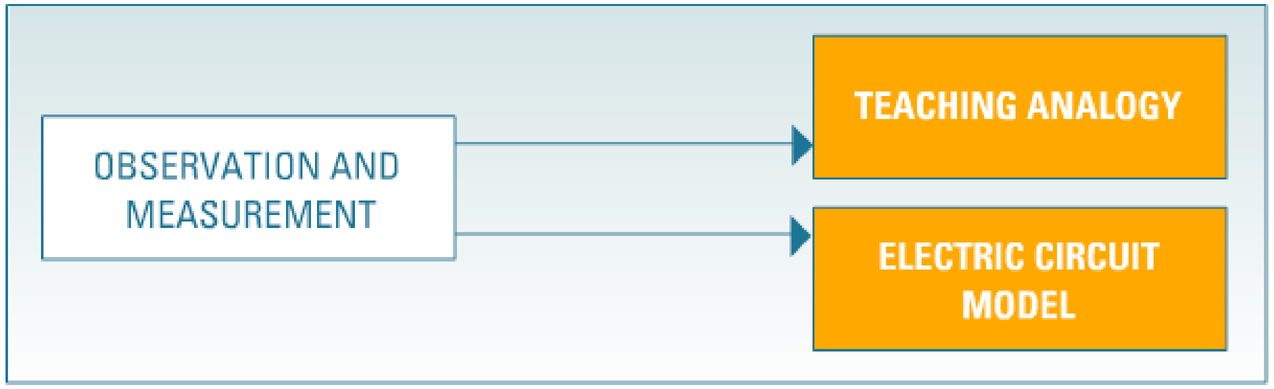
Thinking about the teaching

Consider again how to draw on the three key elements in sequencing the teaching.



Challenge 7: Putting together thinking about two lamps

Once again, our advice is to start with observation and measurement (see what actually happens) and to account for these observations and measurements in terms of the electric circuit model and teaching analogy.



We advise this because sometimes pupils become quite fixed on the idea that the first bulb will get all of the energy when two bulbs are connected in series. With this point in mind, we think that it is a good idea to start with practical observations and measurements. The fact of the matter is that the bulbs are equally dim.

Expressed in terms of the electric circuit model:

Fewer charges pass through either bulb each second so the total energy shifted as each charge passes through the bulbs is shared.

Expressed in terms of the supermarket picture teaching analogy:

With the second supermarket, the bread on each van is shared between the two supermarkets and the vans arrive at each supermarket more slowly.

Challenges for lamps in parallel

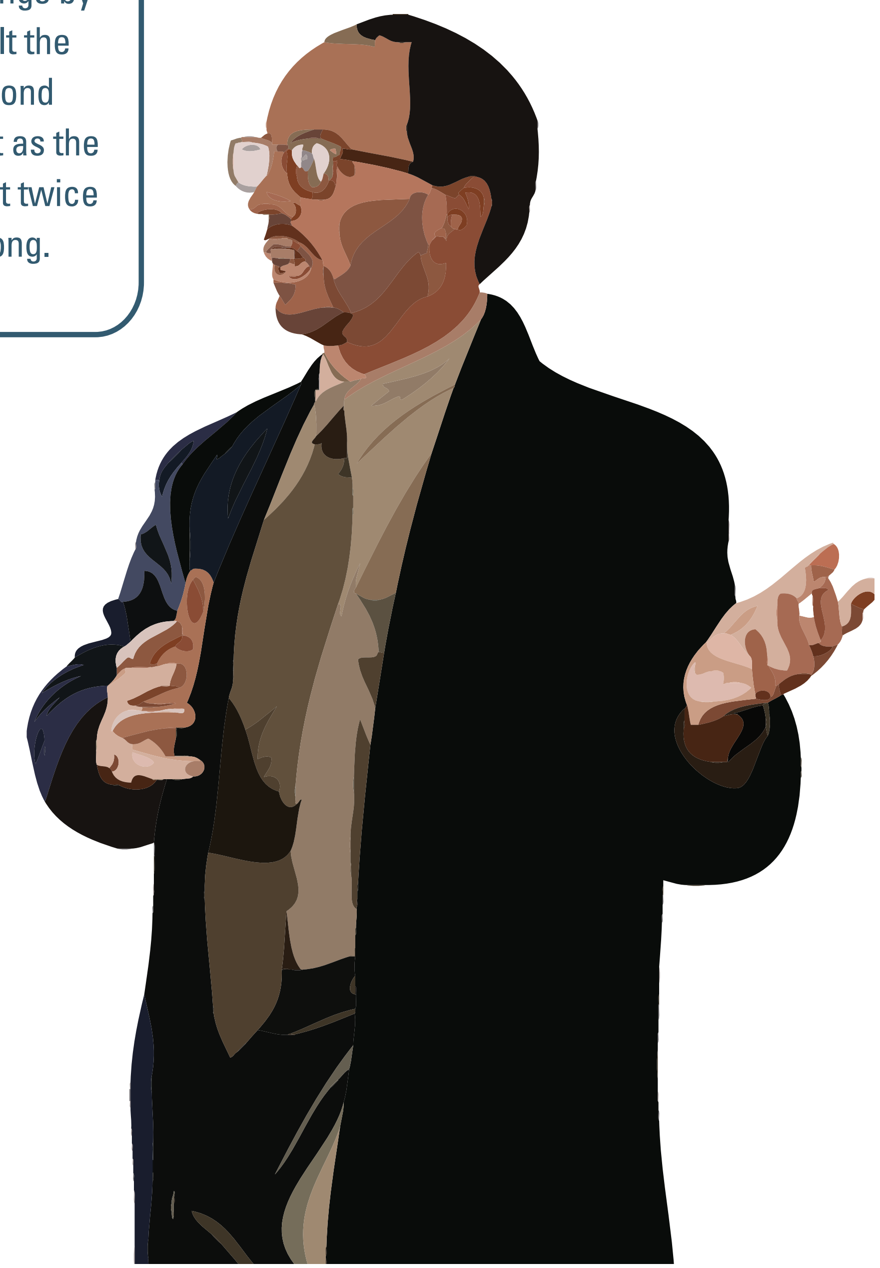
The fact that adding a second bulb in parallel results in the two bulbs being of normal brightness is counter-intuitive for most pupils. Their underlying reasoning is that the single source (or battery) is now being shared between the two consumers (or bulbs) and that they should therefore be dimmer, just like the bulbs in series.

- Challenge 8: Something for nothing?
- Challenge 9: Seeing parallel circuits as two loops
- Challenge 10: So why does the battery go flat more quickly?

These challenges reflect research carried out into alternative conceptions.

Challenge 8: Something for nothing?

Right lines: Energy is shifted to the surroundings by the two bulbs at twice the rate and as a result the battery goes flat more quickly. When the second bulb is added in parallel it is equally as bright as the first one. Energy is shifted by the two bulbs at twice the rate and so the battery does not last as long.



Wrong track: There's no extra battery. We're getting the second bulb's worth for nothing!

Challenge 8: Something for nothing?

The incorrect idea here is that by adding a second bulb in parallel, it is possible to get twice the energy output without further energy cost.

Thinking about the learning

At first it seems as though adding bulbs in parallel gets you something for nothing!

Thinking about the teaching

We suggest two possible ways of addressing this idea of “something for nothing”.

Help pupils make sense of their observations in terms of the battery going flat more quickly;

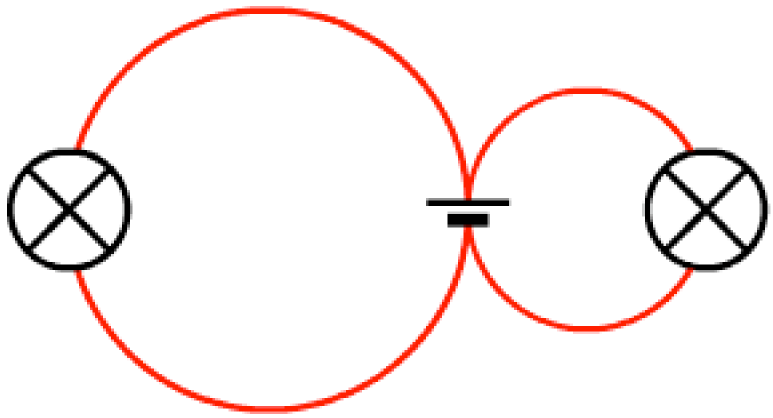
At first it seems as though we’re getting something for nothing, but the drawback is that with the two bulbs in parallel the battery flattens more quickly. We shift the energy from the chemical store of the battery more quickly.

Help pupils picture what is going on in terms of an increased flow of charges through the battery and around the circuit, which results in energy being shifted by the battery and by the bulbs at a greater rate. This detailed approach is discussed in the next challenge.

Challenge 9: Seeing parallel circuits as two loops

Thinking about the learning

If pupils are asked to build a circuit so that one battery lights two bulbs to normal brightness more often than not, they use the single pair of battery terminals to make two circuit loops in the following way:



When the circuit is constructed and drawn in this way as two separate loops, which share a single battery, it makes good sense to pupils that:

- each bulb is of normal brightness
- each bulb has a current through it which is equal to that produced in a simple one battery/one bulb circuit.
- the battery flattens more quickly because it is providing energy for both circuits and bulbs.

These pupil insights provide a very helpful starting point for teaching about parallel circuits.

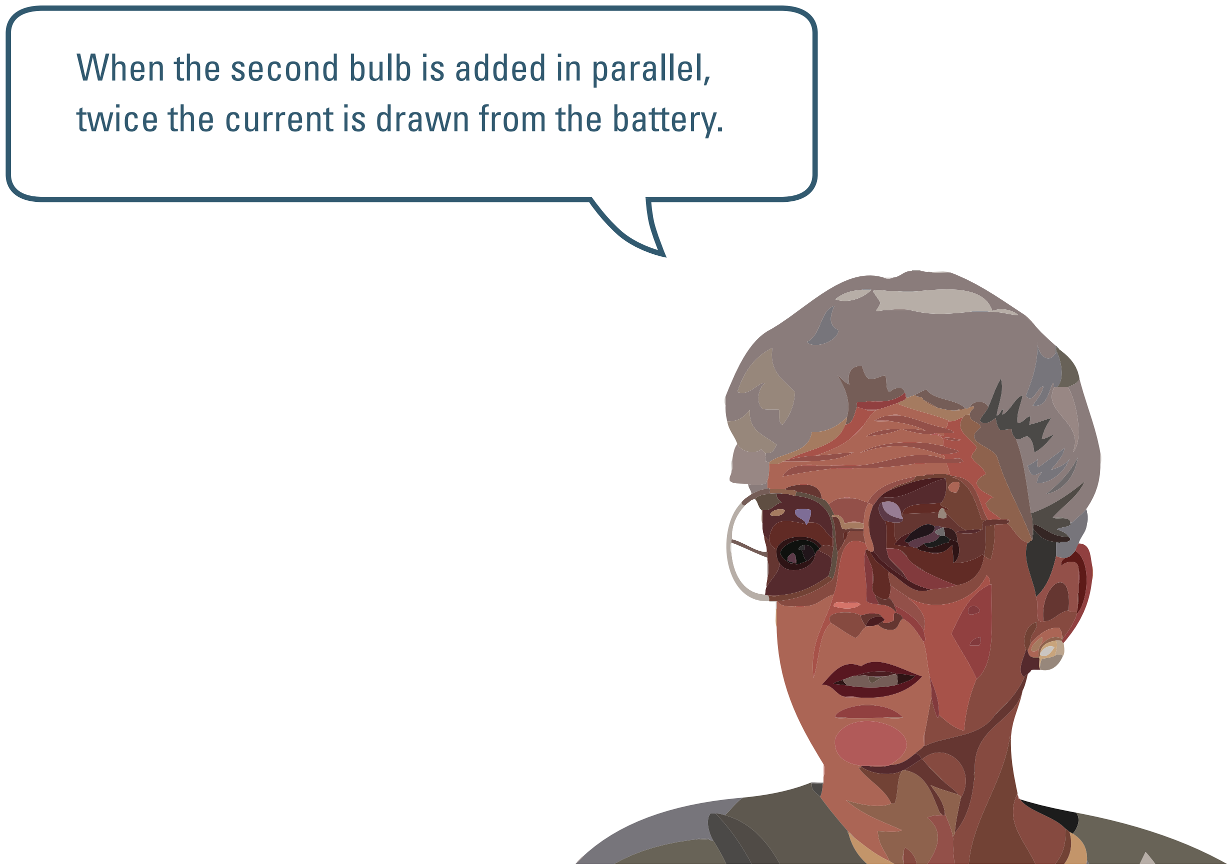
Thinking about the teaching

To help pupils understand parallel circuits as consisting of two loops, and to relate them to these conventional formats, we have found the sequence suggested in the physics narrative to be very useful.

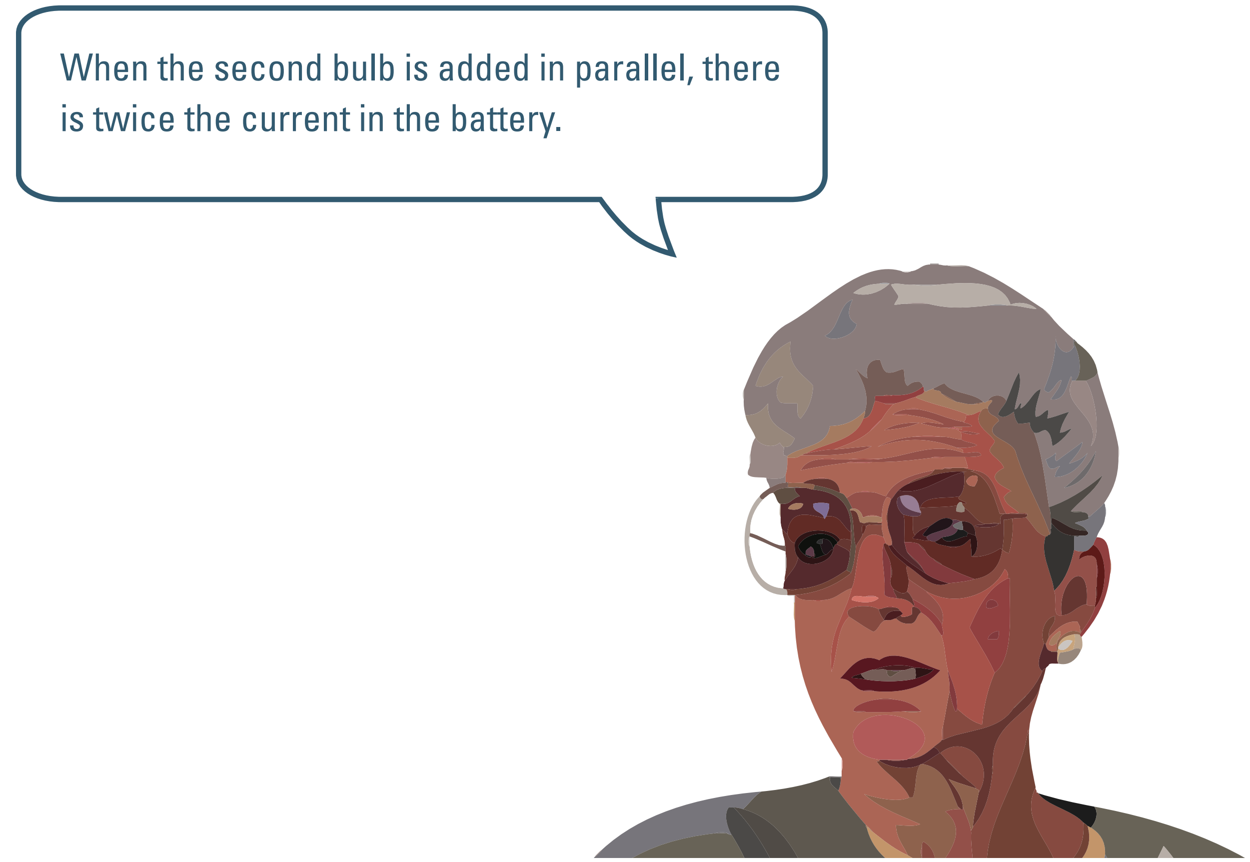
By following this sequence through, the point can be made that in the parallel circuit, each bulb has the same current through it and that a “double current” ($I_1 + I_2$) flows through the battery. The double current shifts energy at double the rate (to the thermal stores of the surroundings).

Careful with your language!

In describing what happens when a second bulb is added in parallel, it is quite common for teachers to use phrases such as:



Such expressions are potentially misleading in that they paint a picture of the battery providing the additional current. Instead, it is the additional charges from the second loop which flow through the battery. It would be better simply to say:

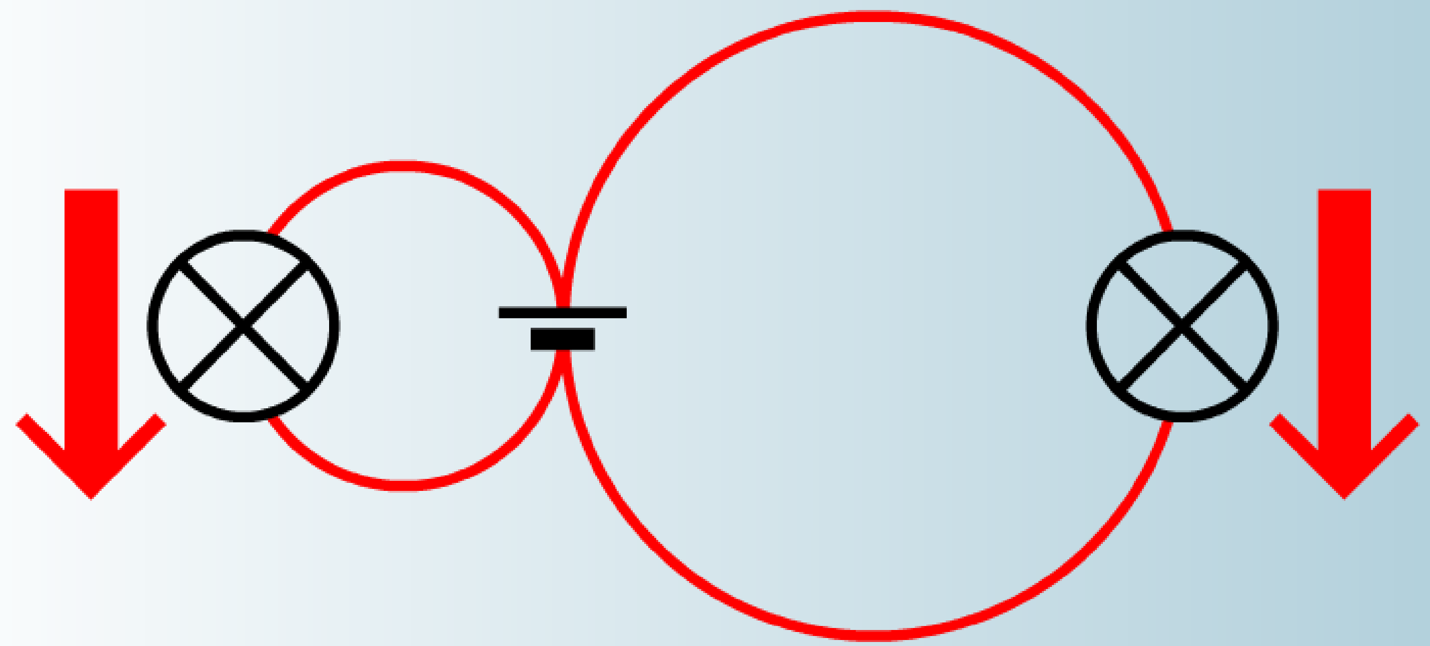


Same circuit, different circuit diagrams

At this point in the teaching it is worth exploring with pupils other representations for parallel circuits, showing that the same circuit can be drawn with different circuit diagram formats.

Introducing parallel circuits

Draw the parallel circuit as two loops:



current through battery = current in left loop and current in right loop
current in right loop = current in left loop

STEP 1 of 3

Challenge 10: So why does the battery go flat more quickly?

Thinking about the learning

The key point here is that when the second bulb is connected in parallel, the current in the battery doubles. This means that double the number of charges are flowing through the battery each second. With double the number of charges, energy must be shifted by the battery to surroundings at twice the rate. So, the energy store of the battery empties more quickly.

Thinking about the teaching

In terms of the electric circuit model

OK, so with one battery and one bulb, we can picture the charges moving through the battery. When a second bulb is added in parallel, an extra loop of charges is provided. The number of charges passing through the battery each second is therefore doubled. So, with the second loop, energy is shifted by the battery and by the bulbs at twice the rate and the battery will go flat more quickly.

In terms of the rope loop

With one loop, I have to work to keep the rope moving and Julia feels her hand warming up as she grips the rope. If I add a second loop of rope, I now need to increase my rate of work to keep both loops going and both Julia and Anita feel their hands warming up. Of course, in this case I get tired more quickly!

In terms of the supermarket picture

Imagine the bakery supplying a second supermarket, which is set up with its own "loop" of vans. At any time there will be twice the number of vans passing through the bakery and taking bread away to each supermarket. So, the stock of bread in the bakery will get used up in half the time.