epiSTEMe Teaching Notes

Electricity: electrical circuits

Overview of the Teaching Notes

INTRODUCTION

This module on ‘Electrical Circuits’ is one of four topic-specific modules that have been developed as part of the epiSTEMe project (Effecting Principled Improvement in STEM Education). The Appendix outlines the epiSTEMe teaching model, and the way in which its principles have been encapsulated across the four modules.

The module that follows relates to National Curriculum requirements for Key Stage 3 teaching about electricity. It builds on material that will have been covered in Key Stage 2, and paves the way for more detailed treatment in subsequent teaching. It is well known that students commonly develop inappropriate mental models about electric circuits. These lead to alternative conceptions that often continue and undermine performance throughout many years of teaching, making electricity a challenging topic for students and teachers. This module attempts to rise to the challenge, by applying the messages for teaching from contemporary theory and research.

The understandings that students are asked to develop to make sense of electrical circuits rely upon abstract ideas (such as potential difference, or ‘voltage’) and application of models at the sub-microscopic level (e.g. of electrons moving through wires). It is known that such ideas make considerable demand upon students. The epiSTEMe module responds to this challenge by focusing on the role of models in building up an understanding of what is going on in circuits. The models that have been recommended are not scientific models, but teaching models to help students make sense of electric circuits. These models have strengths but also limitations that we ask the students to explore. A key feature of the epiSTEMe module, then, is that there is a strong focus on the nature and status of models in science. We have designed this module so that learning about an aspect of the nature of science (model development), and learning about a specific content area (electric circuits), are mutually reinforcing. Practical work is used to provide the evidence that is considered when evaluating the models. In this way the module is designed to help teach aspects of three main areas of the KS3 curriculum: Key concepts (1.1 Scientific thinking), Key processes (2.1 Practical and enquiry skills, 2.2 Critical understanding of evidence), as well as Range and content (3.1 Energy, electricity and forces). By asking students to work with and evaluate models in the context of evidence collected during practical work in class, the theoretical aspects of the topic are embedded in a personally relevant context.

Structure of the module

As detailed in these Teaching Notes, the module starts, after a brief warm-up activity, with a short Pre-Test. Instructions for administering it are included.

The main sequence of activities then follows. The sequence is set out in these Teaching Notes, and is supported with a Study Booklet for students and a set of Projection Slides for classroom use. The sequence has been organised into Lessons, notionally of about or a little under an hour. To help in planning how to fit Lessons into sessions of a different length, or in adapting to unplanned circumstances, each Lesson has been chunked into shorter Parts. Some Lessons end with optional homework to be used at your discretion. In case you do not wish students to take Study Booklets out of school, homework exercises have been copied onto separate sheets as well as into the Booklets.

The module closes with a short Learning Perceptions Questionnaire to be completed by the students followed by an Immediate Post-Test. Instructions are included in these Teaching Notes.

Finally, around 4 weeks after completion of the module, the students sit a Deferred Post-Test without prior notice.

Implementing the module

We ask that you follow the module fairly closely in order to ensure that students in different classes and schools cover more or less equivalent material. However, you will need to translate the plans into a form that will work for your particular class, and our main request is that you do this in a way that seeks to maximise the development of students' understanding of key concepts. Use your discretion to decide whether certain activities require more or less emphasis and more or less time than set out in the notes that follow.

There are also certain aspects of the lessons, which we would ask you not to alter. A key feature of the module is that it includes a large amount of student thinking and talking. Try to ensure that, as far as possible, time for this thinking and talking is preserved. Likewise, these activities have been designed to allow students to formulate their own ideas about topics. Research shows that this will facilitate effective talk and thinking, and so aid progress in understanding. So while the lessons should guide students in developing a 'scientific' view, we ask you (and any assistants working with you) to help them to test and refine their own ideas rather than giving them ideas yourself. The point is to lead or support student activity rather than to proceed immediately to 'correct answers'.

The tasks that we have designed for collaborative activity in small groups should be effective regardless of ability or gender composition, or the existing social relations between group members (e.g. friendships). Within limits, they should also be effective regardless of group size. However, when groups become very large, students can sometimes experience difficulties with managing the dialogue. For instance, some students can get left out or groups can split into subgroups. Large groups may also lead to spectators in practical work. For that reason, we ask that the students normally work in groups of two, three or four.

The electricity module is designed to occupy a sequence of approximately nine one-hour teaching lessons (including time for the pre-test and immediate post-test – some time will be needed in a later lesson for the delayed post-test). The order of the episodes has been designed to support student learning, but the precise division into lessons is flexible to meet the needs of particular schools.

Most students will benefit from working through all the activities, however it is indicated where some material may be considered as 'extension' work that may be omitted for some classes or some groups within mixed ability classes.

As the module integrates a key aspect of learning about 'how science works' alongside learning about one of the key physics themes in the lower secondary science curriculum, some teachers may wish to spread the work over a slightly longer sequence of lessons.

The group-work activities are structured to require the use of thinking together to develop explanations; teacher-led sections will shift between dialogic episodes to collect and value student ideas and authoritative episodes to present the science 'story'. Many of the group activities have a Predict-Observe-Explain structure, where it is important that students initially make predictions and explain their reasons, *before* they start working with apparatus. With some classes it may be important for the teacher to actively structure the activity to check that groups have made reasoned predictions before they are allowed to build circuits (see p.22).

It is important is to allow sufficient time for the activities undertaken to allow dialogic teaching, where students are given space and time to express and explore their ideas both in group work and in teacher-led segments of lessons.

Practical work

Many of the lessons include practical work done in groups, and it is often suggested that this is reinforced by teacher demonstrations with a demonstration circuit and/or simulation software. (If you do not already use such software and wish to consider this, a suitable source is suggested in the Appendix.) It is assumed that in all student practical work the cells and lamps used in circuits will have the same ratings. It is important that all the apparatus is tested by the school science technicians before lessons. So, for example, where one cell is used to power two lamps in series, the lamps should be chosen so that they clearly glow. If necessary instructions and diagrams may need to be customised to ensure practical work is effective if changes to apparatus are required. A summary of lesson requirements is included in the Notes for technicians.

The Teaching Notes and the module PowerPoint presentation

In these teaching notes we focus upon the sequence of key teaching and learning activities. These are organised as a sequence of lesson parts, within nominal lessons. However, whilst the sequence of activities is important, we recognise that there needs to be flexibility to allow teachers to meet the needs of particular classes, timetabling constraints etc. The timing of activities, and the division of the sequence into lessons, should therefore be seen as intended for guidance. The Teaching Notes are complemented by a presentation (in the form of a PowerPoint file), which includes the slides referred to in the teaching notes. This presentation includes a range of additional slides that may be useful as the basis for extra starter/plenary activities where time allows for this.

Lesson 1

Overview
The teaching sequence begins with an opportunity to start thinking about electrical circuits.

Time
Approximately 30 minutes.

Aims
To remind students of their prior learning about, and to begin to problematise, the familiar phenomena of electrical circuits.

Structure
The lesson is in four parts.
- *Part 1*: REVIEWING CIRCUIT DIAGRAMS (5-10 minutes)
- *Part 2*: WHAT IS GOING ON IN THE CIRCUIT? (15+ minutes)
- *Part 3*: THE 'BIG CIRCUIT' (10-15 minutes)

Resources
Part 1: REVIEWING CIRCUIT DIAGRAMS
- Slide 1
- Handout: Four circuits

Part 2: WHAT IS GOING ON IN THE CIRCUIT?
- Slide 3
- Demonstration circuit: simple lamp circuit

Part 3: THE 'BIG CIRCUIT'
- Slide 4
- Demonstration circuit: very large lamp circuit with lamp and switch at opposite ends of the teaching room (National Strategies document: 'Explaining how electric circuits work' (2008), pp.10-11.)

LESSON 1, PART 1: REVIEWING CIRCUIT DIAGRAMS

Objectives

To remind students of the work they have done on electricity at KS2, and in particular to review electric circuit diagrams.

Time

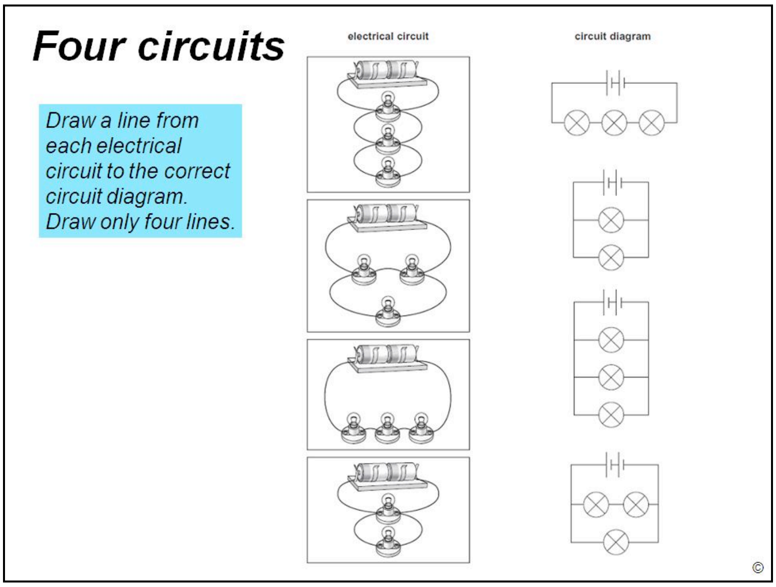
5-10 minutes.

Resources

- Slide 1: Four circuits
- Handout: Four circuits

Activities

- Give out one hand-out per pair of students. This shows a question from a past SATs test (SAT KS3-2008-Paper2 Q1, tiers 3-6) that we found most students found straightforward *before* studying the topic in Year 7. Ask the students to agree in their pairs which of the circuit diagrams is meant to stand for each of the electrical circuits pictured. When they have agreed, they should use a pencil to draw connecting lines.
- Monitor students working, and hold a brief full class plenary on this activity.



Slide 1

LESSON 1, PART 2: WHAT IS GOING ON IN THE CIRCUIT?

Objectives

To focus the students' minds on electric circuits (previously studied, but perhaps not well understood at primary school), and elicit their current thinking about and what is going on in a circuit.

Time

15 minutes, or longer depending on the group.

Resources

- Slide 2: Bulb light
- Demonstration circuit as shown in slide

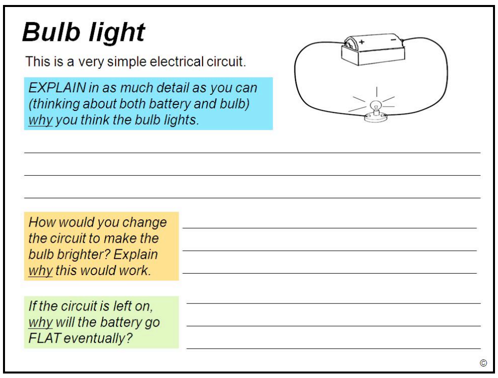
Activities

Whole-class activity

- Show the students the *Bulb light*, which is a simple circuit, without discussion of what is going on beyond simple descriptive terms (pointing out that the lamp is glowing, and that the circuit includes a cell/battery).

Small-group activity

- In pairs, the students should work on the *Bulb light* task.
- Remind the students that they should try to agree their answers before they write anything down.
- Collect in the students' responses to review before subsequent lessons, to inform points to be made during teaching. It may be useful to refer the students back to their original answers at the end of the module, so they can reflect on any changes in their thinking.



Slide 2

Note

Research shows that students of this age commonly hold alternative conceptions (misconceptions) of what is going on in circuits, and find learning the scientific models very challenging.

The instructions for this activity (and the worksheet that is adopted here) are to be found in the National Strategies document: 'Explaining how electric circuits work' (2008), pp.7-9. A useful summary of common student ways of understanding circuits is also provided here.

LESSON 1, PART 3: THE ‘BIG CIRCUIT’

Objectives

To focus the students’ minds on key aspects of thinking about electrical circuits, in particular to think holistically: changes in one part of the circuit influence the rest of the circuit (effectively) instantaneously.

Time

10-15 minutes.

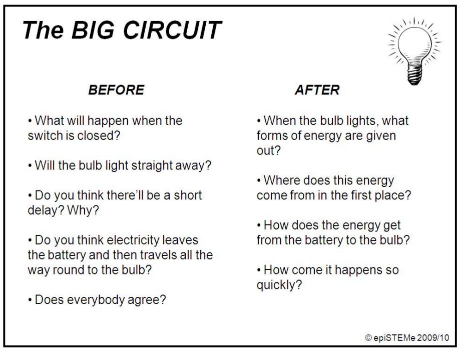
Resources

- Slide 3: The BIG CIRCUIT
- The demonstration will require setting up a circuit that will run around the entire room. The lamp must light instantly. Of course lamps take a finite time to warm up enough to glow: so it is important that the set up uses a lamp/supply combination that appears to give a glow from the lamp *as soon as* the switch is closed.
- From the National Strategies document: ‘Explaining how electric circuits work’ (2008), pp.10-11. “The BIG circuit consists of a 12-volt power supply and a large bulb (12 volt/24watt) set up with insulated connecting wire running round the perimeter of the room. It is a good idea to tape the wire to the walls of the room and to mark it with ‘BIG CIRCUIT’ labels all the way around.”

Activities

Whole-class activity

- Show the students a ‘big’ circuit (with lamp and switch at opposite ends of the room).
- Invite students to predict how quickly the lamp will light when the switch is closed and ask them to give reasons for their predictions.
- Let the students comment on each other’s ideas, but do not close down the discussion.
- Then close the switch (the lamp should light immediately).
- Ask the students to comment on what they observed, and why – again inviting a range of views and ways of explaining the observations.



Slide 3

Note

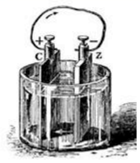
The lamp in ‘the big circuit’ lights as soon as the switch is closed because it does not depend upon some substance moving from the battery to the lamp. A circuit is a continuous conducting path, with mobile charges (usually electrons) at all points. Closing the switch in effect allows each electron to repel the next instantly. See the IoP materials on *Support Physics Teaching 11-14* for background on this. This will be counter-intuitive to many students, who tend to think (quite naturally) of circuits sequentially. Unfortunately such thinking is inconsistent with what happens in circuits (e.g. the flow of current at any point depends on the total resistance in a circuit, not just in that part of the circuit).

LESSON 1, HOMEWORK (OPTIONAL)

Alessandro Volta

What can you find out about Alessandro Volta?

What did the first electric batteries look like and what were they used for?



Slide 4

Lesson 2

Overview

Lesson 2 introduces ideas about how we represent, and can productively think about, electrical circuits. As well as supporting learning about electrical circuits, this material offers opportunities to explore wider curriculum objectives for learning about the nature of science (‘how science works’), in terms of the importance of technical forms of representation in communicating scientific information, and in emphasising how scientists look to models to help develop scientific explanations.

Time

Approximately 60 minutes.

Aims

To build on students’ curiosity about what is going on in an electrical circuit, and to consider two aspects of how science works: (a) scientists using analogy as one source of explanations, and (b) using conventional representations (here circuit diagrams) to communicate scientific ideas.

Structure

The lesson is in three parts:

- *Part 1*: A WAY OF THINKING ABOUT CIRCUITS (10-15 minutes)
- *Part 2*: INTRODUCING ANALOGY (20-25 minutes)
- *Part 3*: BREAKING THE CIRCUIT CODE (25 minutes)

Resources

Part 1: A WAY OF THINKING ABOUT CIRCUITS

- Slides 5-10

Part 2: INTRODUCING ANALOGY

- Slides 11-18

Part 3: BREAKING THE CIRCUIT CODE

- Slides 19-20

LESSON 2, PART 1: A WAY OF THINKING ABOUT CIRCUITS

Objectives

To introduce a model in terms of supermarket delivery vans (something within students' everyday experience), which can act as a way of thinking about what is going on in circuits.

Time

10-15 minutes.

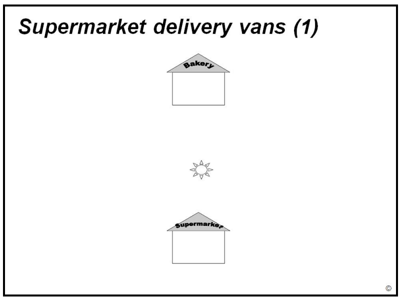
Resources

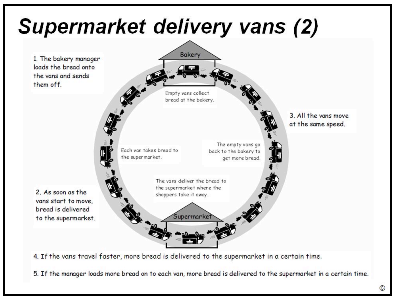
- Slide 5: Supermarket delivery vans (1)
- Slide 6: Supermarket delivery vans (2)
- Slide 7: Supermarket delivery vans (3)
- Slide 8: Supermarket delivery vans (4)
- Slide 9: Circuit diagrams
- Slide 10: The BIG CIRCUIT diagram

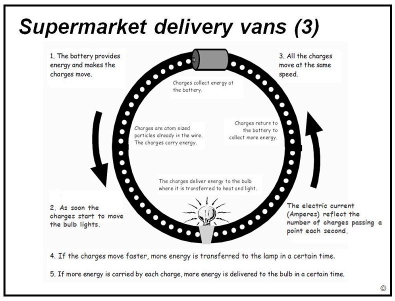
Activities

Whole-class activity

- Show the students the *Supermarket delivery vans (1) – (3)* slides and tell the students that someone has suggested this supermarket delivery van scenario might be a useful way of thinking about what is going on in circuits.
- The supermarket picture offers a model of what is happening in the circuit. There are delivery vans 'around' the 'circuit' between the bakery and the supermarket, just as there are electrons able to move in all parts of the circuit.
- A key feature of this supermarket delivery van model is that goods are transferred from a bakery to supermarkets, but the vans themselves continue to move around the circuits. In the same way, electrical circuits allow energy to be transferred (e.g. from battery to lamp) whilst the electrons continuously circulate. (This is very important, as students do not really discriminate between these two types of flow in a circuit). We can think of the electrons as being on a continuous conveyor belt, being loaded with energy at one point, and distributing it to one or more other points in the circuit.
- Tell the students that you are using a model (in this case, an extended analogy) to help understand what is going on in electrical circuits. Make them aware that you are only making a comparison (so there are ways the supermarket model is not like an electric circuit) and that models are used in this way as 'thinking tools' scientists.



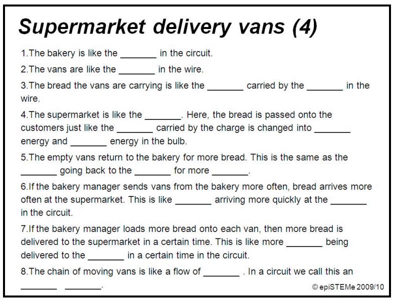


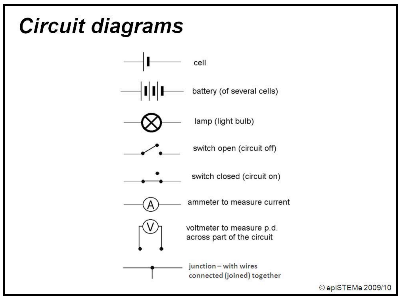


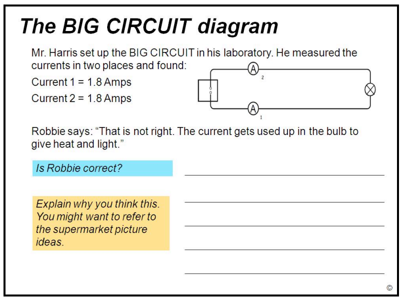
Slides 5-7

Small-group activity

- Get the students to work in groups on *Supermarket delivery vans (4)* and *The BIG CIRCUIT diagram*. The slide *Circuit diagrams* helps students understand the symbols.







Slides 8-10

Whole-class activity

- Elicit suggestions on *Supermarket delivery vans (4)* and *The BIG CIRCUIT diagram* from different groups and ask the students to explain their reasoning.
- Invite comments from other groups, again asking the students to explain their reasons.
- If there is a range of ideas, this should be continued until the main ideas have been explored. If groups have generally agreed, there is no need to extend the discussion.
- Tell the students that you think they have produced some interesting ideas, and you will return to them in later lessons. Reiterate that this is how science works: that creative scientists are those that are able to generate interesting ideas that can be tested.

Note/Teaching Point

- Source and details of the Supermarket Picture are available in the document 'Teaching Science for Understanding: Electric Circuits' by Andy Hind, John Leach, Jenny Lewis and Phil Scott, and available from http://www.education.leeds.ac.uk/research/cssme/ElecCircuitsScheme.pdf.
- It is very important that students are clearly aware that we do not take the supermarket model as a literal description of what is going on in the circuit. (When students take teaching models too seriously, they can later find it difficult to move beyond the model.)
- However, it is also important that the students realise this is not a trivial comparison, but an example of the kind of thinking that scientists do to help them develop their understanding of the world. So a student who feels that they already understand electric circuits can be reassured that this is not a waste of time, as they are learning about the use of models in science – also an important part of the curriculum.

LESSON 2, PART 2: INTRODUCING ANALOGY

Objectives

To introduce analogies (and more generally models) as important features of learning about the nature of science ('how science works') and develop understanding of how they can help us make sense of circuits.

Time

20-25 minutes.

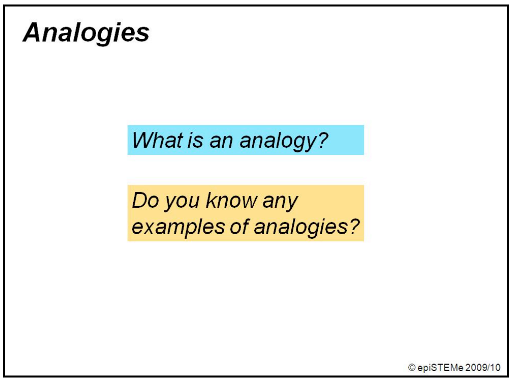
Resources

- Slide 11: Analogies
- Slide 12: Heart-pump analogy
- Slide 13: Space-internet analogy
- Slide 14: Ear-conveyor belt analogy
- Slide 15: Pros and cons of analogies
- Slide 16: Electric circuit analogy
- Slide 17: Electric circuit-underground map analogy
- Slide 18: Limits of analogies

Activities

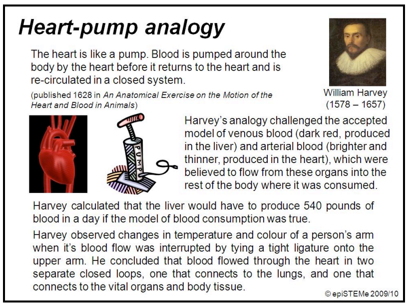
Whole-class activity

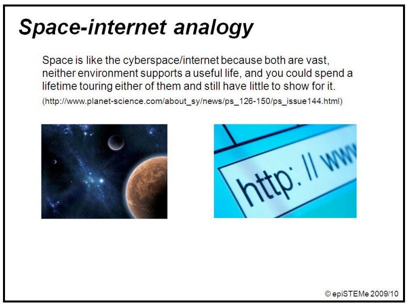
- Using the *Analogies* slide, ask the students if they know what the word analogy means, and/or if they know any examples of analogies.

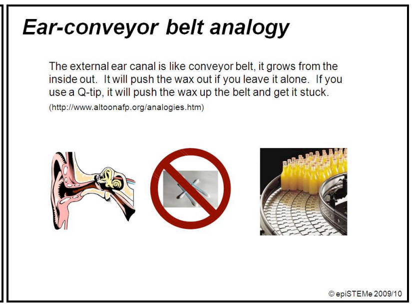


Slide 11

- Then tell the students that analogies have been very useful to scientists, as they have struggled to make sense of the world. Analogies can also be useful in learning about new ideas.
- Discuss some examples of analogies from history (e.g. *Heart-pump analogy*) and modern life (e.g. *Space-internet analogy, Ear-conveyor belt analogy*).

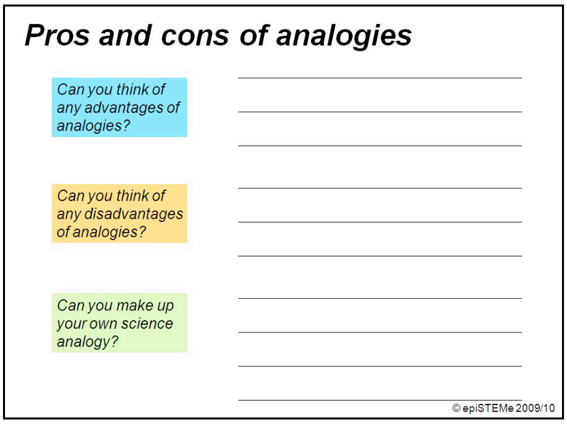






Slides 12-14

- Using the *Pros and cons of analogies* slide, ask the students if they can think of any pros and cons of using analogies. Be open to the students' ideas, and ask them to comment on each other's suggestions in constructive ways.



Slide 15

Small-group activity

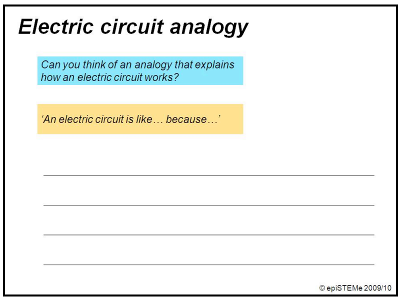
- Get the students work in pairs to suggest their own analogies for familiar (e.g. KS2) science concepts (lower part of *Pros and cons of analogies* slide). During this activity, make sure (a) that the students explain their ideas to their partner; (b) that the students are looking for analogies (ways in which the scientific concept is like the everyday analogue) rather than just similarities, e.g.:

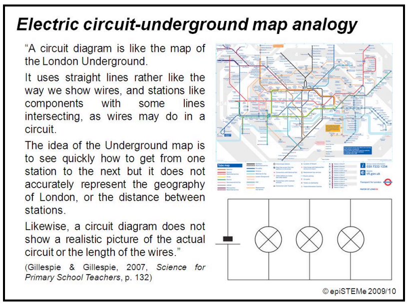
A flower is like a clock, because they are both round	This is a similarity, but not really an analogy
A flower is like a shop window, because the flower presents what the plant has to offer to bees in a similar way to how a shop window shows off what the shop has available to shoppers.	This is an analogy as there is a mapping of structure between the target and analogue.

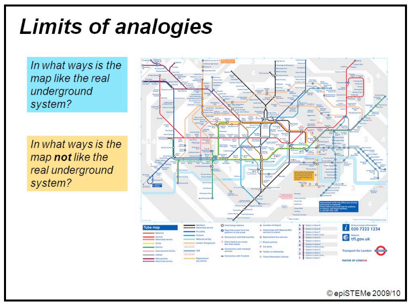
- It will be useful to make a note of a few good examples suggested by class members for the plenary.

Whole-class activity

- Ask the students for examples of interesting (or funny) analogies. Lead a dialogic exchange exploring some examples. Point out that some of the most useful scientific ideas have been considered strange (quirky, odd) when they were first proposed: e.g. that the earth moves around the sun; that all living organisms have common ancestors, etc.
- Then shift to a more authoritative mode, to discuss a few strong examples where the analogies effectively map ideas from the analogue on to the target. Some backup examples are:
    - A filter is a bit like a security guard because a security guard *only lets some* people get into a building, and a filter *only allows some* materials to pass through (e.g. into the flask).
    - A micro-organism is a bit like gossip as you *cannot see* gossip but it can *sometimes damage* relationships, just as you *cannot see* micro-organisms but *some can damage* your health.
    - Blood is a bit like the postman, because the postman will *take* the letters round *to different* houses, just as blood *takes* the oxygen *to different* parts of the body.
- Using the *Electrical circuit analogy* slide, ask the students to think up an analogy that they think might help them understand how an electric circuit works.
- Project a map of the London Underground (*Electric circuit-underground map analogy*) and ask the students to suggest a) ways in which the map is like the underground system and b) ways in which the map does not reflect the real underground system.







Slides 16-18

Note/Teaching Point

- A model is only like the thing it represents in some ways. To be a good model it has to reflect the aspects of the thing represented that is of interest. The London Underground map is a good model if you want to get from King's Cross to Earl's Court. The London Underground map is NOT a good model if you are an engineer who has to work out how much steel will be needed to replace the rails on the central line.
- Models have to be fit for purposes. When our purposes change, we may have to change the model we use.

LESSON 2, PART 3: BREAKING THE CIRCUIT CODE

Objectives

To introduce, or reinforce, the use of circuit diagrams to represent electrical circuits.

Time

25 minutes.

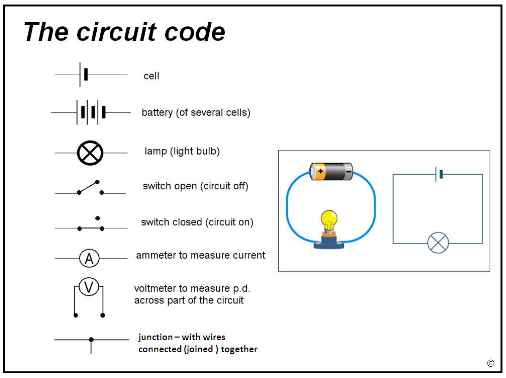
Resources

- Slide 19: The circuit code
- Slide 20: Breaking the circuit code
- Six demonstration circuits that match those shown on the 'Breaking the circuit code' side. The small-group activity will require setting up 6 circuits in the classroom *before* the groups start working.

Activities

Whole-class activity

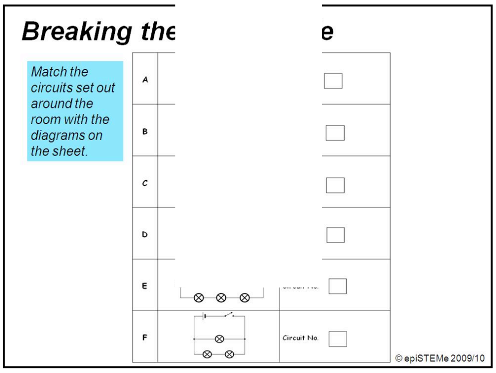
- Using the circuit code slide, introduce the common symbols used in circuit diagrams.
- Explain that circuit diagrams are a special kind of model that is useful to *represent* circuits in science. Circuit symbols are like a special (graphical/diagrammatic) language or code.



Slide 19

Small-group activity

- Organise the students into groups to work on *Breaking the circuit code*. Each group must try to match the circuits set out around the room with the diagrams on the sheet.



Slide 20

Whole-class activity

- Once the groups have completed the task, lead a discussion to find out which groups have broken the code. If students have found this activity straightforward, then this will be a short discussion. However, if groups disagree on some responses, explore their reasoning (ask them to explain their choices) for disputed responses, before closing down the discussion by explaining the right answers.

LESSON 2, HOMEWORK (OPTIONAL)

Your alien pen pal

You have an alien pen friend who lives on a planet just like earth - with seas, and trees, and mountains, and fluffy clouds. However, animal life has ***evolved*** very differently on his planet and he has a very different ***anatomy*** to you - he is just like a big blob!

Your friend is intrigued when you write about parts of your body, as he does not have legs and arms or a nose or ears. Your friend wonders what teeth are like, what your pulse is like, what your skeleton is like, and so on.

Can you think of some things that these things are like and explain it to your friend in that way?

Use sentences like this one: Teeth are like _______ because _________

*Remember, I am not asking you to describe teeth, pulse, skeleton, and so on, but to suggest things that are in some way **like** these things to see if that helps your friend understand.*

Slide 21

Lesson 3

Overview

Lesson 3 focuses on electric current in the context of series circuits. The lesson explores two further models for thinking about electrical circuits, to help students appreciate the nature of models (i.e. useful thinking tools, rather than realistic descriptions), and understand that multiple models can be useful in learning about the same concepts.

Time

Approximately 55 minutes.

Aims

To help develop the scientific concept of current both qualitatively through a number of models, and as a quantity that can be measured.

Structure

The lesson is in two parts:

Part 1: BUILDING A SIMPLE SERIES CIRCUIT AND MEASURING CURRENT (25-30)

Part 2: MAKING SENSE OF CURRENT (25-30 minutes)

Resources

Part 1: BUILDING A SIMPLE SERIES CIRCUIT AND MEASURING CURRENT

- Slides 22-26
- Sufficient electrical kit for each student group to build the circuits (each group will need lamp, switch ammeter, cell and connecting leads)
- Teacher demonstration circuit (e.g. using large demonstration ammeter if available) or suitable simulation software

Part 2: MAKING SENSE OF CURRENT

- Slides 27-30
- Rope for rope loop model
- Marbles for role-play activity

LESSON 3, PART 1: BUILDING A SIMPLE SERIES CIRCUIT AND MEASURING CURRENT

Objectives

To focus the students' minds on the concept of current. To elicit students' prior thinking, and to provide experience to challenge 'misconceptions' about the nature of current flow in circuits. To learn to use ammeters to measure current. (This activity also reinforces earlier work on circuit diagrams.)

Time

25-30 minutes.

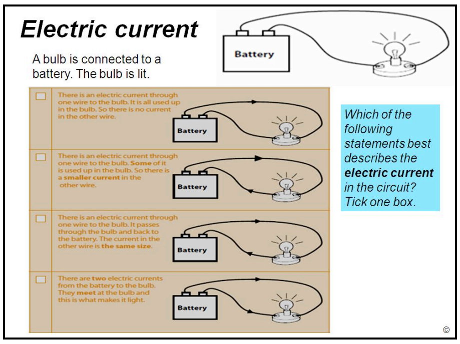
Resources

- Slide 22: Electric current
- Slide 23: Electric current in a simple circuit (1)
- Slide 24: Electric current in a simple circuit (2)
- Slide 25: Electric current in a simple circuit (3)
- Slide 26: Electric current in a simple circuit (3) continued
- Sufficient electrical kit for each student group to build the circuits (each group will need lamp, switch ammeter, cell and connecting leads) – see slides 23-26.
- Teacher demonstration circuit (e.g. using large demonstration meter if available) or suitable simulation software (see appendix)

Activities

Small-group activity

- Get the students to work in pairs on *Electric current* (5 min). Research suggests that students commonly expect current to be 'used-up' in a lamp (as they do not fully distinguish current from energy), although earlier work in the module may have already challenged this thinking.
- Remind the students to try to find an agreement and give reasons.



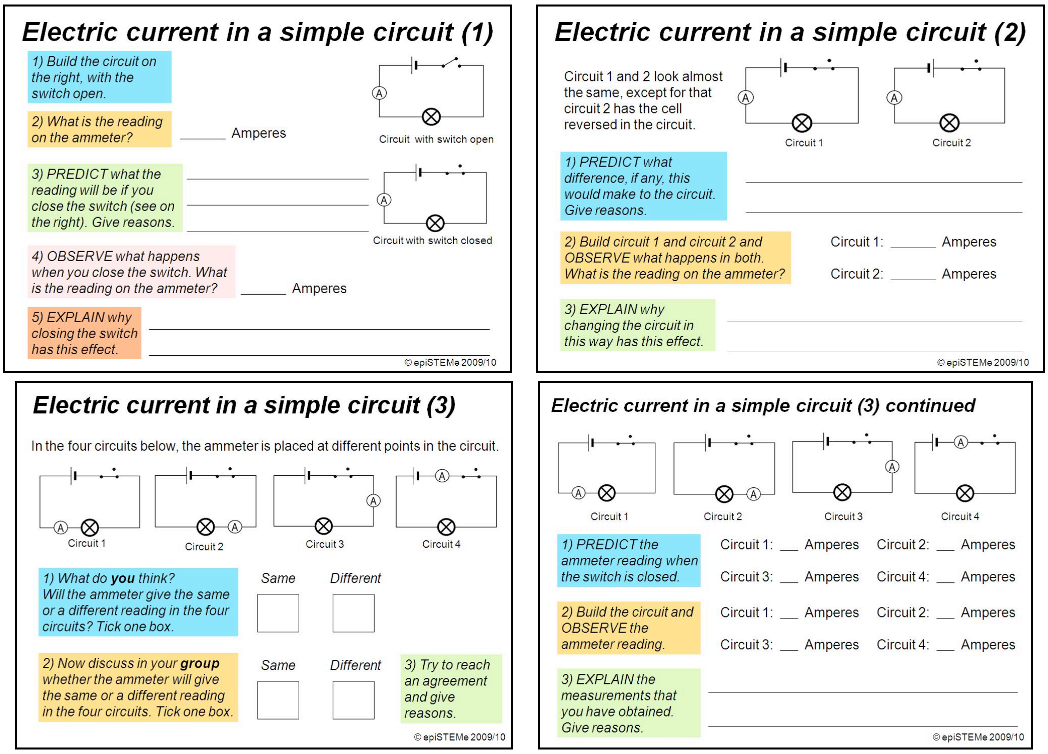
Slide 22

Whole-class activity

- Get the students back into whole-class mode and lead a discussion of their views about current flow in circuits.
- Do not evaluate responses at this stage. Remind students that a key part of the work of scientists is generating ideas and possible explanations, that can be subject to thorough discussion and experimental testing.

Small-group activity

- Organise the students into small groups to work on *Electric current in a simple circuit*. This activity provides the real world experience of circuit phenomena to support the later whole-class discussion.
- Emphasise that groups must follow the sequence of tasks outlined in their Study Booklet so as to follow the predict-observe-explain (P-O-E) approach (see the note below, p.22). Explain that this is the way scientists work, by making predictions, and then testing them to see if they provide useful explanations.
- The students should discuss and agree their answers at each point before moving on. Make sure that they are following this procedure during group work.
- Check during group work that the students' results are consistent with the key idea that current is conserved all around a series circuit.



Slides 23-26

Whole-class activity

- Ask the groups what they have found out and whether it surprised them (cf. their comments on *Electric current* above). Be prepared to either demonstrate the key findings with a clearly visible demonstration circuit or suitable simulation software (see Appendix) projected onto the screen/whiteboard.

- At the end of this episode it is important that the students accept the key finding, i.e. current is the same at different points in the circuit.

Note

- The activity *Electric current in a simple circuit (1)* reinforces Lesson 1, Part 3 and introduces quantifying and measuring current.
- The activity *Electric current in a simple circuit (2)* introduces the significance of the polarity of the cell. With some types of meter, no reading will be obtained if the meter connections do not match the cell/battery polarity.
- The activity *Electric current in a simple circuit (3)* provides the students with direct experiential evidence that current is conserved all around a series circuit.

P-O-E – Predict-Observe-Explain

- P-O-E, Predict-Observe-Explain is a well-established approach to support students in thinking about the purposes of practical work, and to help them both to focus on the target phenomena during practical work, and to think about what their observations could mean.
- For P-O-E to work, students MUST spend time on making a prediction, *before* making their observations. It is also important that this is more than just a guess. So, as elsewhere in the epiSTEMe lessons, students must give reasons for their suggestions. Student should be encouraged to discuss their predictions both to explain their own reasoning, and to make efforts to appreciate, and if appropriate critique, the arguments of others in the group.
- This activity is therefore a good place to ensure that the class group rules for talk are being followed. Students should be reminded to listen to each other's ideas, and to offer evaluations that are both courteous, and supported by reasoning. As elsewhere in epiSTEMe lessons, students should seek to come to an agreement on their prediction(s) before undertaking the observations.
- Some groups and classes will be able to apply the P-O-E approach effectively with minimal teacher input. However in many cases, especially where students have not used this approach before in other topics, it will be important for the teacher to manage the activity until groups show they can follow the procedures. In these cases it is recommended that the teacher ask the group to work first *only* on the prediction, and then stop the class for a brief sharing of ideas between groups. You should ask groups both what their predictions are, and for their reasons. It would be helpful to highlight where students are using analogies and models in their thinking, but you should NOT evaluate any responses: just praise students for giving reasons for their ideas.
- Slide 85, at the end of the Powerpoint presentation, may be useful here. The word 'predict' can be shown, and only after you are confident all groups have completed this stage, the world 'observe' can be revealed. It is equally important to make sure the group spend time at the end of the activity thinking about what they actually observed, and trying to explain it (i.e., reveal the word 'explain' on slide 85).
- Slide 85 can be copied and added to the series of slides at each point you feel that this level of teacher management of the P-O-E activities is appropriate for a particular class. (Or it can be copied to a second presentation to avoid changing slide numbers.)

LESSON 3, PART 2: MAKING SENSE OF CURRENT

Objectives

To introduce the scientific concept of current, and to explore models of current. To provide students with ways to think about circuits, and to grasp the concept of the conservation of current (the counter-intuitive idea that the same value of current is measured all around the circuit) to make sense – so reinforcing their empirical work.

Time

25-30 minutes.

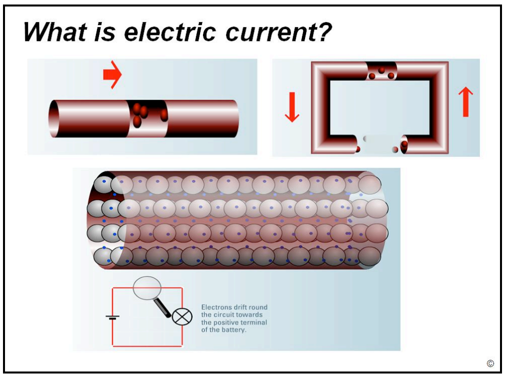
Resources

- Slide 27: What is electric current?
- Slide 28: Supermarket delivery vans recap
- Slide 29: Rope-loop model
- Slide 30: Role-play simulation
- Rope for rope loop model. "A long length of rope is needed, which can be passed in a BIG loop (prompting links to the BIG circuit) around all of the members of the class. Lightweight (4–6 mm diameter) rope used by climbers is ideal. If the rope is too heavy the frictional forces are too big and it is very difficult to get the rope moving across thirty pairs of fingers." National Strategy: *Explaining how electric circuits work*, p.13
- Marbles for role-play activity

Activities

Whole-class activity

- Present to the students in authoritative mode the model of current as electron flow as an accepted scientific model of electric current. Tell the students that scientists have developed models to explain electrical circuits. A model that has proved very useful is to think of electric current as a flow of tiny particles, electrons, which carry a charge. In a circuit enormous numbers of these tiny electrons move around the circuit. You may also want to use an animation showing this model dynamically (e.g. Supporting Physics Teaching 11-14, Electricity & Magnetism, Section 2 – 'More about electric currents', 'Physics Narrative').



Slide 28

- Explain to the students that electric current is measured in Amperes, which tells us how much charge is passing that point in a circuit each second. As each electron has a tiny, tiny charge, a very small current still represents an enormous number of electrons moving through the ammeter. Try to present a picture of electric current as one of huge numbers of electrons 'drifting around the circuit at a rather sedate pace'. Tell the students that electrons are absolutely tiny, but that in the diagrams of '*What is electric current?'* the electrons are drawn VERY much bigger so that they can be seen. Remind students that often in science we use representations (which are kinds of models that distort objects to emphasise key features. Remind them that in an earlier lesson (Lesson 2, Part 2) they saw an example of this in the Underground Map.
- Probe students' background knowledge of 'charge'. If students are not familiar with or are vague about this concept, it will be useful to refer to lightening and simple electrostatic phenomena (such as a charged comb attracting dry hair).

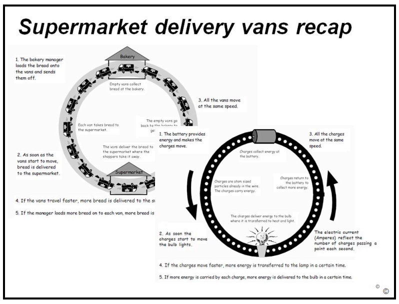
Whole-class activity

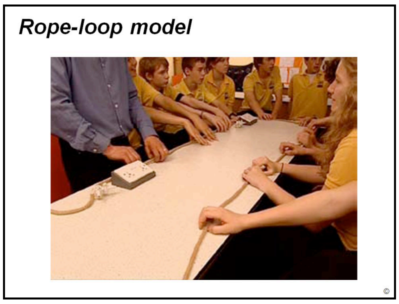
- Discuss 3 models with the class to help students think about circuits.

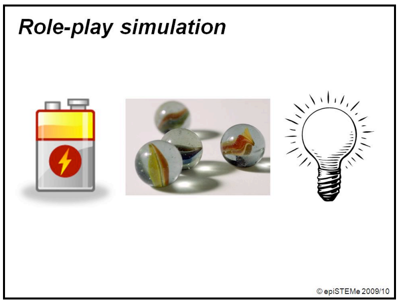
  Supermarket-delivery van model (introduced earlier in the module). Reinforce the distinction between energy (transferred from the power source to other parts of the circuit) and current (the flow of 'vehicles' that travel round to deliver the energy).

  Rope-loop model. Carry this out as a practical demonstration with a group of students helping (see Note below for information to set up). A key feature is that *all of the rope* loop moves when the circuit is working. Another key feature is that the same rope can circulate around the circuit of students indefinitely. Get the students to explore the role of the 'battery'. The resistance of students' hands is analogous to the electrical resistance of lamps (or other loads) and the person acting as the cell/battery can apply more or less force (which can later be linked to varying p.d.)

  Role-play simulation. The students play out the role of charge carriers/electrons. The students walk around the classroom (like electrons) receiving a marble (or other suitable proxy for energy, e.g. matches which are lit at the lamp) from the teacher (as the cell) and depositing it into a cup held by one student at the opposite end of the classroom (as a load, such as a lamp). The students complete the circuit after delivering their load. Note how for the simulation to work, students must start at different points in the circuit – they do not all begin at the power source.
- After each demonstration/activity, explore the students' thinking about both (a) how the model is like an electric circuit, and (b) about ways in which it is not a good model.
- Reiterate that in exploring models in this way, the students are 'doing science' just like the scientists who developed the model of electrical current being due to the movement of a great many tiny electrons.





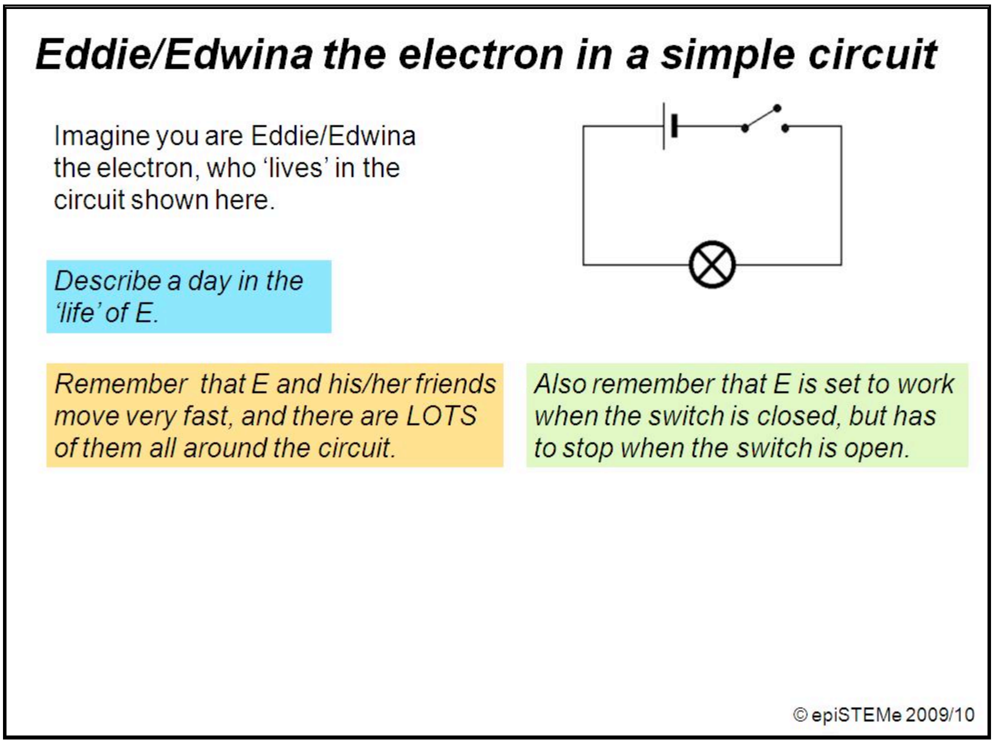


Slides 28-30

Notes

- Research has shown that even when students have seen practical demonstrations showing that current is the same all around the circuit, they are likely to mis-remember this to fit their previous ideas some weeks or months later. In this episode you help students build mental models that 'make sense' of their results to help them learn the scientific understanding.
- For more information on the rope-loop model, see National Strategy: *Explaining how electric circuits work,* p 12 and the video at http://www.teachersmedia.co.uk/videos/electrical-circuits .

LESSON 3, HOMEWORK (OPTIONAL)



Slide 31

Note

In Lesson 3 we say "Try to present a picture of electric current as one of huge numbers of electrons 'drifting around the circuit at a rather sedate pace'." Yet slide 31 refers to E moving very fast! This apparent contradiction relates to scale. At the human scale, electrons drift around the circuit at a modest pace – e.g. perhaps moving a millimetre in 10 seconds – but when considered at the scale of the electron itself this is VERY fast indeed. If pupils raise this, you might want to use the example of a fast intercity train or a passenger jet being monitored by an observer based on the moon. The passengers may feel they are moving very fast, but at the global scale they make modest progress. If any students watch Grand Prix races on television, they will have seen camera shots of speeding cars superimposed with a graphic of where leading drivers are on the course: the car symbols on the graphic move very slowly around the racing circuit! That graphic makes a great model of electrons moving around a circuit.

(Actually electrons move much faster than their drift around the circuit would seem, as they have a large random motion - a bit like gas particles, another analogy - upon which is superimposed their modest drift due to the p.d. across the circuit. It is usual to ignore the much larger random component of movement as our scientific model of electrons moving around a circuit is a simplification – although the random motion is much greater, it does not play a role in explaining the circuits.)

Lesson 4

Overview

Lesson 4 introduced the notion of potential difference, as a distinct (from current) feature of electrical circuits. Students gain first hand experience of measuring p.d., and considering how current and p.d. 'behave' in circuits with more than one load (i.e. lamp).

Time

Approximately 60 minutes

Aims

To introduce the concept of p.d. (potential difference), and emphasise the distinction between current and p.d. through exploring the effect of having several loads (i.e. lamps) in a series circuit.

Structure

The lesson is in two parts:

- *Part 1*: BUILDING A SIMPLE SERIES CIRCUIT AND MEASURING P.D. (15-20 minutes)
- *Part 2*: BUILDING SERIES CIRCUITS WITH DIFFERENT NUMBERS OF LAMPS (25-45 minutes)

Resources

Part 1: BUILDING A SIMPLE SERIES CIRCUIT AND MEASURING P.D.

- Slides 32-35
- Sufficient circuit kit for each group of students to build circuits for *p.d./voltage in a simple circuit* (each group will need cell, lamp, switch, voltmeter as well as connective leads)
- Teacher demonstration circuit (e.g. using large demonstration voltmeter if available) or suitable simulation software

Part 2: BUILDING SERIES CIRCUITS WITH DIFFERENT NUMBERS OF LAMPS

- Slides 36-41
- Sufficient circuit kit for each group of students to build circuits for *p.d./voltage in a simple circuit* (each group will need cell, 2 lamps (3 if final part of lesson taught through student group work), switch, ammeter, voltmeter as well as connective leads) – see slides 38-41
- Teacher demonstration circuit (e.g. using large demonstration meters if available) or suitable simulation software

LESSON 4, PART 1: BUILDING A SIMPLE SERIES CIRCUIT AND MEASURING P.D.

Objectives

To learn how to measure p.d. in simple circuits. To discriminate p.d. from current. To appreciate that p.d. must be applied across a complete circuit (conducting path) for current to flow.

Time

15-20 minutes.

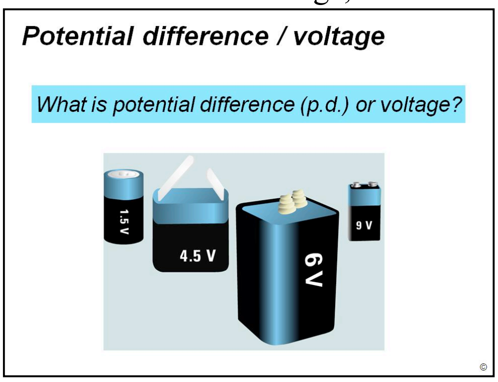
Resources

- Slide 32: Potential difference / voltage
- Slide 33: p.d./voltage in a simple circuit (1)
- Slide 34: p.d./voltage in a simple circuit (2)
- Slide 35: Difference between current and p.d.
- Sufficient circuit kit for each group of students to build circuits for 'p.d./voltage in a simple circuit' (each group will need cell, lamp, switch, voltmeter as well as connective leads) – see slides 33-34.
- Teacher demonstration circuit (e.g. using large demonstration voltmeter if available) or suitable simulation software.

Activities

Whole-class activity

- Elicit any prior knowledge and understanding of the terms potential difference or voltage. Explain that potential difference is the scientific term for voltage, and is commonly abbreviated to p.d.
- Using the slide *Potential difference / voltage*, explore the students' ideas about the significance of the p.d. of common cells and batteries (e.g. 1.2 V rechargeable cells, 1.5V dry cells, and 3V, 6V, etc batteries). See if the students can suggest why cells of very different size (AAA, AA, C, D etc) will provide the same p.d.

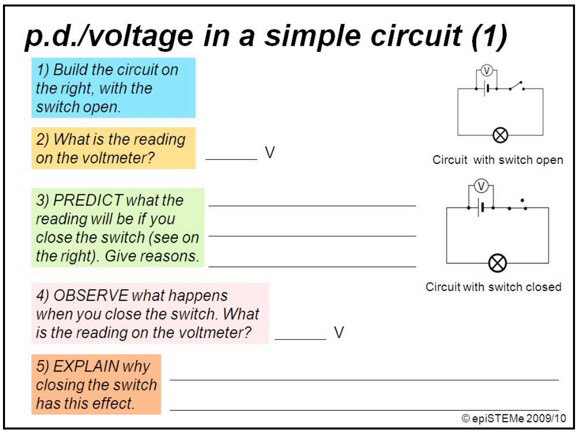


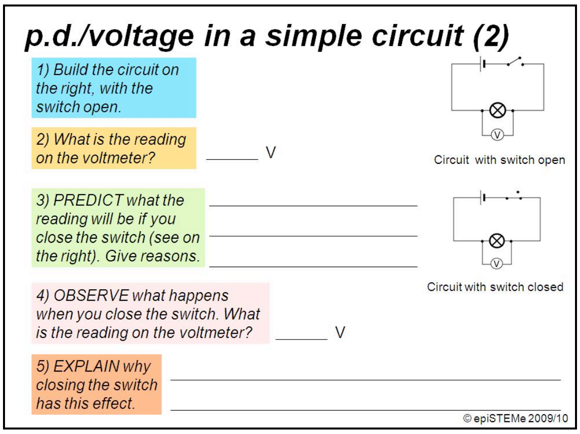
Slide 32

- Introduce the idea of potential difference (p.d., often called 'voltage' by non-scientists) as being *like* a force which pushes current round a circuit. Beware not to suggest p.d. 'is' a force, we are using another analogy here!
- Emphasise that p.d. is different from current. We need a different measuring instrument (voltmeter) to measure p.d., which is connected up in a different way to an ammeter.

Small-group activity

- Get the students to work in small groups on *p.d./voltage in a simple circuit (1) – (2)*.
- Emphasise that groups must follow the sequence of tasks outlined in their Study Booklet so as to follow the predict-observe-explain (P-O-E) approach (see note on p.22: consider showing slide 85). Remind students that this is how science works: by scientists trying out ideas and testing their understanding. Check that the students discuss the questions and agree what to write at each stage.
- In *p.d./voltage in a simple circuit (1)*, check (in authoritative mode) that the groups find that the reading is not significantly changed on closing the switch.
- In *p.d./voltage in a simple circuit (2)*, check (in authoritative mode) that the groups have no p.d. across the lamp with the switch open, but on closing the switch find a similar p.d. across the lamp as they measure across the cell.

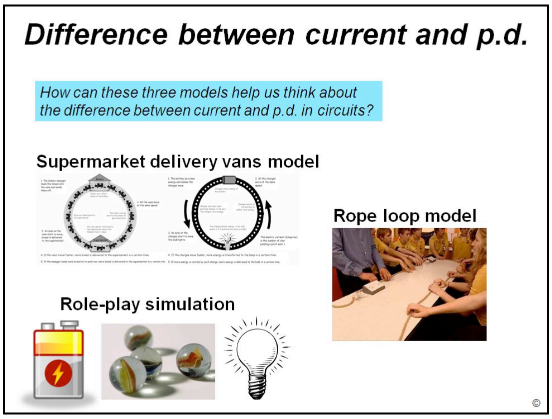




Slides 33-34

Whole-class activity

- Lead a whole-class plenary emphasising what the groups have found, and their explanations. If necessary, reinforce findings by showing a demonstration circuit, or suitable simulation software.
- Present the students with *Difference between current and p.d.* and refer them back to the models discussed in episode 3.2. Ask the students how these models help us think about the difference between current and p.d. in circuits.



Slide 35

LESSON 4, PART 2: BUILDING SERIES CIRCUITS WITH DIFFERENT NUMBERS OF LAMPS

Objectives

To reinforce ideas about current being conserved in a circuit, whilst giving students practice at building circuits, taking electrical measurements and developing explanations using scientific language and models.

Time

25-45 minutes depending upon the class, and on whether the final section is taught through group practical work or teacher demonstration.

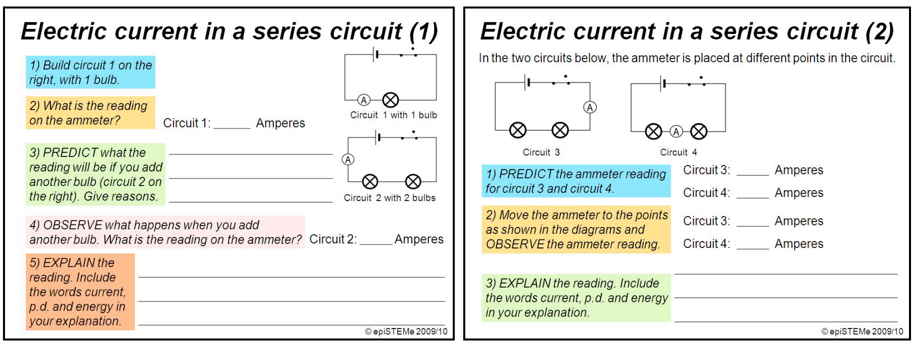
Resources

- Slide 36: Electric current in a series circuit (1)
- Slide 37: Electric current in a series circuit (2)
- Slide 38: p.d./voltage in a series circuit (1)
- Slide 39: p.d./voltage in a series circuit (2)
- Slide 40: Electric current in a series circuit with three bulbs
- Slide 41: p.d./voltage in a series circuit with three bulbs
- Sufficient circuit kit for each group of students to build circuits for 'p.d./voltage in a simple circuit'. Each group will need cell, 2 lamps (3 if final part of lesson taught through student group work), switch, ammeter, voltmeter as well as connective leads – see slides 36-38.
- Teacher demonstration circuit (e.g. using large demonstration meters if available) or suitable simulation software.

Activities

Small-group activity

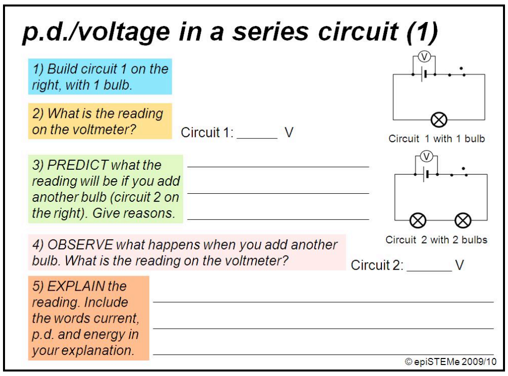
- Set up the students in their groups to work on *Electric current in a series circuit (1)-(2)*. Remind them of the ground rules – to discuss questions, and try to agree answers to write down.
- During group work, also check that the students are getting the 'same' (within experimental error) readings at all points in their circuit.

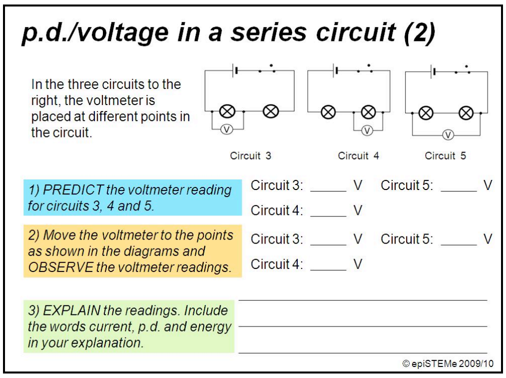


Slides 36-37

Small-group activity

- Still in groups, students should move on to *p.d./voltage in a series circuit (1)-(2)*. This is another P-O-E activity (see note on p.22: consider showing slide 85).
- Remind the students of the difference between ammeters and voltmeters and how they are connected in circuits.
- During activity *p.d./voltage in a series circuit (2)*, check that the groups are getting results that show the p.d. measured across the two lamps individually sums to the p.d. across both lamps (and the p.d. across the cell(s).) (You may need to refer to 'experimental error', i.e. the limit of accuracy of any measurement.)





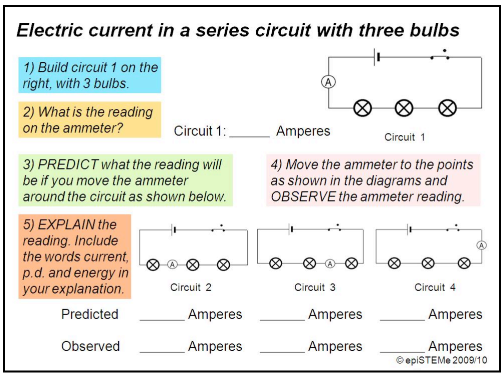
Slides 38-39

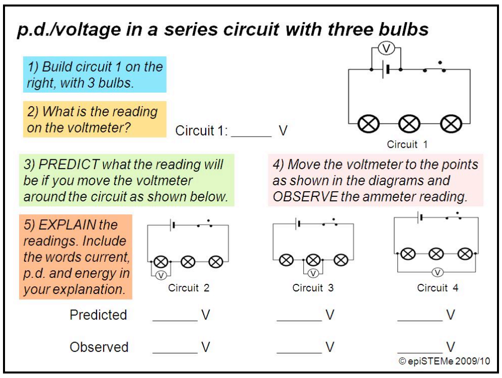
Whole-class activity

- *Bring the cl*ass together for a plenary and review. Ask groups to report and explain their findings.
- Taking an authoritative mode, emphasise the distinction between current (conserved…) and p.d. (divided around the circuit).
- Be prepared to reiterate findings using either a demonstration circuit or simulation software if needed.

Whole-class activity or small-group activity

- Extend the logic of the practical work by exploring what would happen if there were three lamps (*Electric current in a series circuit with three bulbs* and *p.d./voltage in a series circuit with three bulbs*).
- It may be appropriate to set these two activities for some classes/groups after the previous practical work. With other students, it will be better to lead a discussion and demonstrate the results.
- Introduce the terminology 'series' for the arrangement of several lamps (or cells) on the same conducting path.





Slides 40-41

Lesson 5

Overview

Lesson 5 reinforces learning about p.d. by considering circuits with more than one cell, and develops student thinking about how to model circuits by exploring how the three models introduced to help students think about a simple circuit may be applied to more complex circuits.

Time

Approximately 55 minutes

Aims

To develop student thinking about how to model circuits through considering what happens when several cells are used, and critiquing the three simple models that have been introduced.

Structure

The lesson is in two parts:

- *Part 1*: CIRCUITS WITH DIFFERENT NUMBERS OF CELLS (15 minutes)
- *Part 2*: MODELLING SERIES CIRCUITS (30-40 minutes)

Resources

Part 1: CIRCUITS WITH DIFFERENT NUMBERS OF CELLS

- Slide 42
- Demonstration kit for building circuits (2 cells, lamp, display meters, switch, connecting leads); optional use of simulation software.
- If using group practical work, enough electrical kit for each group to build circuits (each group needs 2 cells, lamp, ammeters, voltmeter, switch, connecting leads) – see slide 42.

Part 2: MODELLING SERIES CIRCUITS

- Slides 43-51
- No practical apparatus is required for this lesson part, but the teacher *may* wish to demonstrate circuits or use simulation software to review previous practical work.

LESSON 5, PART 1: CIRCUITS WITH DIFFERENT NUMBERS OF CELLS

Objectives

To reinforce the distinction between p.d. and current, and to develop understanding of p.d. in a circuit.

Time

15 minutes (depending upon the teaching mode chosen).

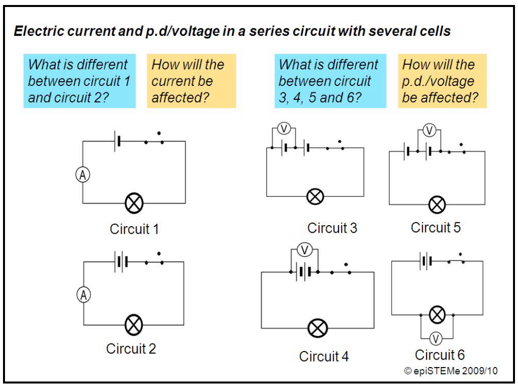
Resources

- Slide 42: Electric current and p.d/voltage in a series circuit with several cells
- Demonstration kit for building circuits (2 cells, lamp, display meters, switch, connecting leads); optional use of simulation software
- If using group practical work, enough electrical kit for each group to build circuits (each group needs 2 cells, lamp, ammeters, voltmeter, switch, connecting leads) – see slide 42

Activities

Small-group activity or whole-class activity

- Where time and equipment allow, the activity *Electric current and p.d/voltage in a series circuit with several cells* could be set up as group work, with a somewhat less rigid structure than previous practical in the module, e.g. the activity slide could be displayed, and students asked to work in their groups to find an answer to the questions posed.
- However, this activity might instead be used as the basis for class discussion, inviting student responses to the questions, asking students to explain their reasons and then asking whether other students agree. This may lead to a consensus that could then be checked (using a demonstration circuit, perhaps reinforced with simulation software). If the students do not agree, it would be possible to identify the 2 or 3 key views, and take a show of hands, recording the tally of support for each: then demonstrate the circuits to see how many students were correct. Remind students that proposing ideas to be tested (many of which will be found to be wrong) is an important part of science.



Slide 42

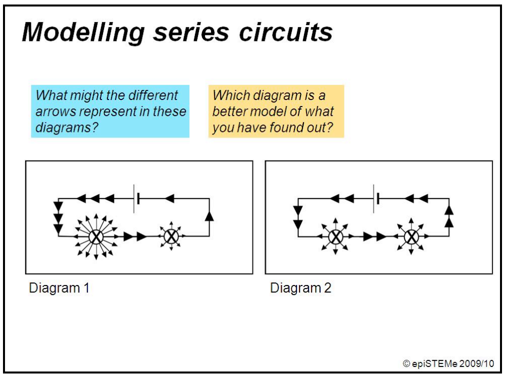
LESSON 5, PART 2: MODELLING SERIES CIRCUITS

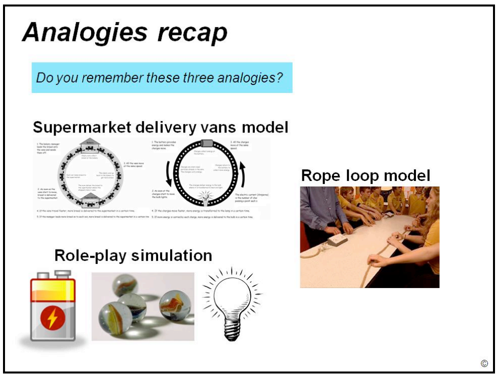
Objectives
To reinforce learning about current and p.d. in series circuits, and to give students opportunities to apply models, express explanations and use scientific language.

Time
30-40 minutes depending on class.

Resources
- Slide 43: Modelling series circuits
- Slide 44: Analogies recap
- Slide 45: Making sense of series circuits (1)
- Slide 46: Making sense of series circuits (2)
- Slide 47: Supermarket delivery vans model in series circuits (1)
- Slide 48: Supermarket delivery vans model in series circuits (2)
- Slide 49: Supermarket delivery vans model in series circuits (2) continued
- Slide 50: Supermarket delivery vans model in series circuits (3)
- Slide 51: Rope-loop model and role-play simulation in series circuits
- No practical apparatus is required for this lesson part, but the teacher *may* wish to demonstrate circuits or use simulation software to review previous practical work

Activities
Whole-class activity
- In whole-class mode, review the findings from the practical work undertaken in previous episodes; using the technical vocabulary (energy, current, p.d., series arrangement).
- Make sure that the students are clear about the conservation of current, and dividing of potential (e.g. across several lamps), in a series circuit. You may want to have demonstration circuits and/or simulation software to show the students key results again if they have not remembered.
- Show the diagrams in *Modelling series circuits* and ask the students to explain with reasons what they think the different arrows might represent in these diagrams, and which diagram is a better model of what they have found out. [The second diagram is a better representation of constant current flow around the circuit and both lamps glowing at the same brightness: but do not dismiss other interpretations that could make sense to the students, such as the arrows on the wires in the first diagram being understood as the energy being carried by the current].
- Show the *Analogies recap* slide and ask the students if they can remember the three models used previously. Elicit a description of the supermarket delivery vans model.

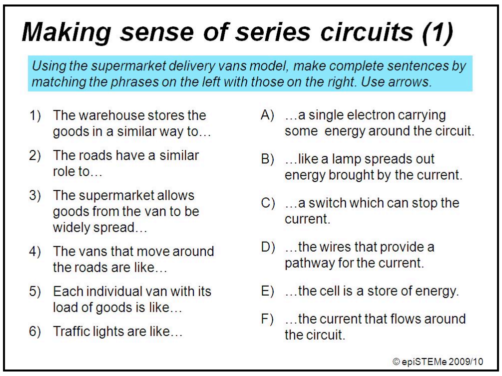


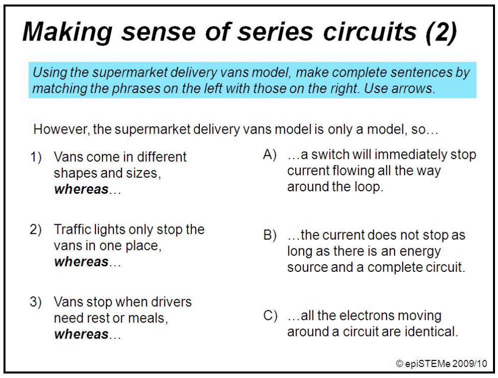


Slides 43-44

Small-group activity

- Get the students to work in pairs or small groups on *Making sense of series circuits (1)-(2)*. Remind them to discuss and agree on their answers.





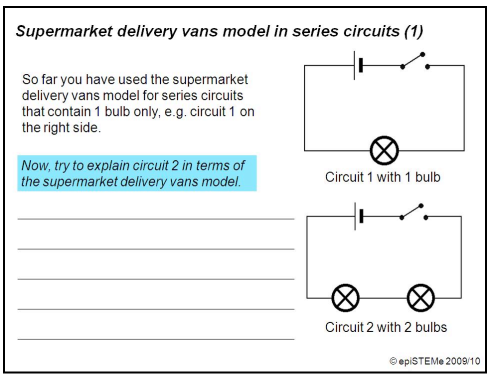
Slides 45-46

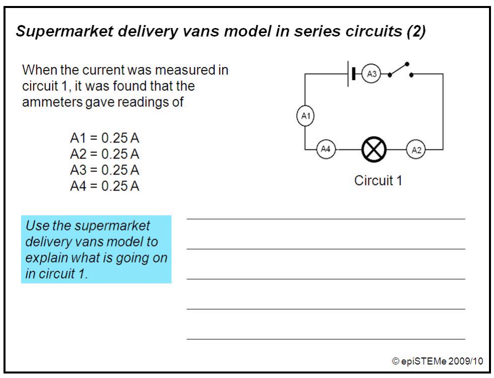
Whole-class activity

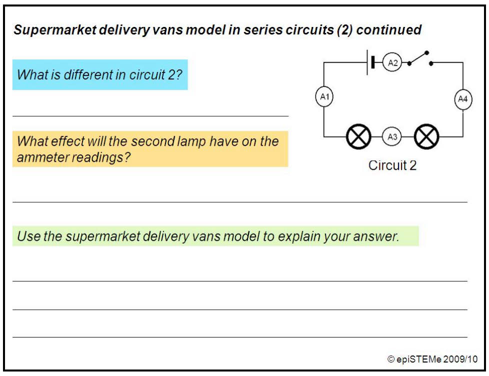
- Debrief in whole class.

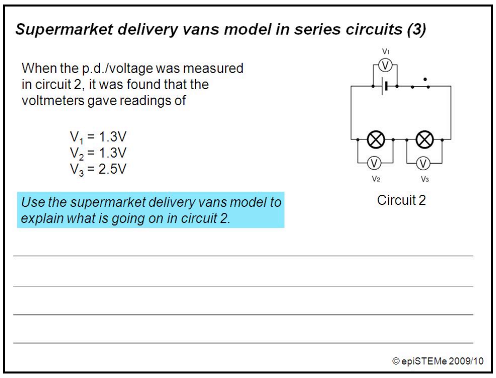
Small-group activity

- Get the students to work in pairs or small groups on *Supermarket delivery vans model in series circuits (1)-(3)*. All students should be able to complete the first activity [*Supermarket delivery vans model in series circuits (1)*]. You may choose to differentiate within the class in terms of how many activities you set.





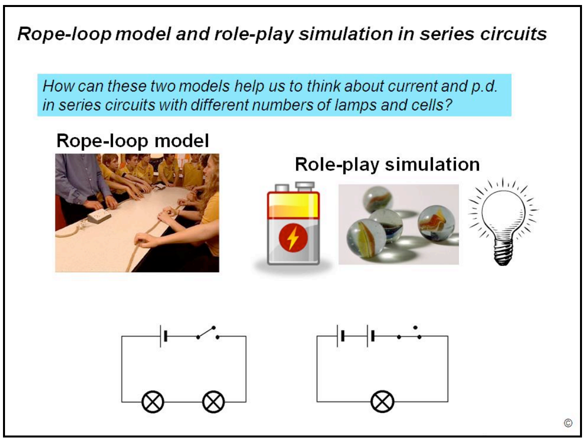




Slides 47-50

Whole-class activity

- Bring the class together for a plenary, find out how the students responded to the activities, and ask them to explain the reasons for their answers.
- In some classes, most students will have completed the activities fairly readily. If some students could not complete the task, or suggest inappropriate responses, go through the answers carefully, and explain them.
- Emphasise how even the most useful models used in science are only like the things they model *to a limited extent*, and so it is important to recognise the limitations of models.
- Using the *Rope-loop model and role-play simulation in series circuits*, discuss (and demonstrate) whether the rope-loop model helps the students think about current and p.d. in series circuits with different numbers of lamps and cells. Also, see if the students can help set up role-play simulations to illustrate how current and p.d. might vary in the circuits with different numbers of lamps or cells. In both cases, focus both on the previous empirical findings, and on the nature of using models to try to understand scientific ideas. It does not matter if the students are not able to fully model what they have found from their practical work in terms of these models, so long as they are able to explain (give reasons for) where they think the models fall short (why they don't seem to 'work' for some points). Finding the limits of models is an important part of doing science.

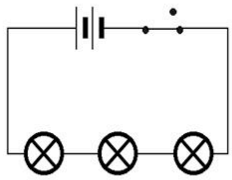


Slide 51

LESSON 5, HOMEWORK (OPTIONAL)

Eddie/Edwina the electron in a series circuit

Imagine you are Eddie/Edwina the electron, who 'lives' in the circuit shown here.



Describe a day in the 'life' of E.

Remember that E and his/her friends move very fast, and there are LOTS of them all around the circuit.

Also remember that E has to use the energy the cells provide to get around the whole circuit.

Slide 52

Stairs and lights

In many houses there are lights above the stairs that have two switches.

This means that the light can always be turned on or off from either downstairs or upstairs. See if you can find out how this is done.

Draw a circuit diagram to the right with one lamp, one cell, and two switches, so that the lamp can always be turned on or off from either switch.

Explain how the two switches can 'independently' control the same lamp.

Slide 53

Lesson 6

Overview

Lesson 6 introduces the idea of circuits with several conducting paths along which current can travel. This provides an additional complication, and so a further context for students to think about how current and p.d. behave in a circuit.

Time

Approximately 60 minutes.

Aims

To introduce the notion of parallel paths, and to explore parallel circuit behaviour.

Structure

The lesson is in two parts:

- *Part 1*: INTRODUCING PARALLEL CIRCUITS (25-30 minutes)
- *Part 2*: POTENTIAL DIFFERENCE AND PARALLEL CIRCUITS (20-30 minutes)

Resources

Part 1: INTRODUCING PARALLEL CIRCUITS

- Slides 54-58
- Three demonstration circuits, with a simple lamp, two lamps in series, two lamps in parallel should be set up (with switches open) for the start of the class – see slide 54
- Preferably use 12V lamps and a suitable supply, so that the effects are clear
- Sufficient electrical kit for each group of students to construct circuits (each group needs a cell, 2 lamps, 3 switches, ammeter and connecting leads) – see slides 54, 55
- Optional: simulation software

Part 2: POTENTIAL DIFFERENCE AND PARALLEL CIRCUITS (20-30 minutes)

- Slide 59: p.d./voltage in a parallel circuit
- Slide 60: Electric current and p.d./voltage in a parallel circuit
- Slide 61: Electric current and p.d./voltage in a parallel circuit continued
- Slide 62: Graphic model of p.d./voltage in a parallel circuit
- Sufficient electrical kit for each student group to build circuits. Each student group needs cell, 2 lamps, 3 switches, voltmeters and connecting leads; each student group undertaking the extension activity with need an additional lamp, switch and ammeter. – see slides 59-62

LESSON 6, PART 1: INTRODUCING PARALLEL CIRCUITS

Objectives

To introduce the distinction between series and parallel arrangements of circuit components, and to allow the students to see how parallel circuits lead to different 'rules' for what is happening in terms of current and p.d. The scientific understanding would be:

	series	parallel
current	The same all the way around	Divided across different parallel branches
p.d.	Divided across components in series	The same across different parallel branches

Time

25-30 minutes depending on class.

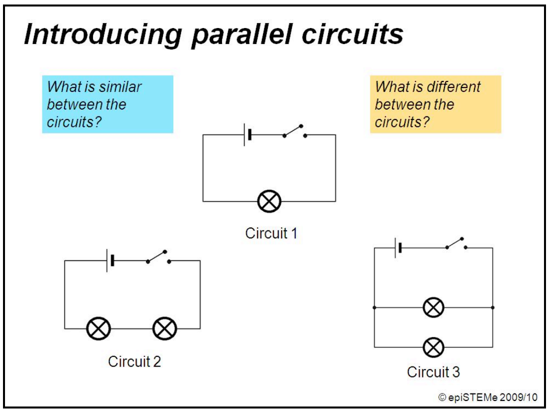
Resources

- Slide 54: Introducing parallel circuits
- Slide 55: Electric current in a parallel circuit (1)
- Slide 56: Electric current in a parallel circuit (2)
- Slide 57: Graphic model of current in parallel circuits
- Slide 58: Graphic model of current in parallel circuits continued
- Three demonstration circuits, with a single lamp, two lamps in series, two lamps in parallel should be set up (with switches open) for the start of the class – see slide 54. Preferably use 12V lamps and suitable supply, so that the effects are clear
- Sufficient electrical kit for each group of students to construct circuits (each group needs cell, 2 lamps, 3 switches, ammeter and connecting leads) – see slides 54, 55
- Optional: simulation software

Activities

Whole-class activity

- Give a whole-class demonstration of the three circuits shown on the slide *Introducing parallel circuits*. Do not close the switch *yet*. Begin by showing a simple circuit with two lamps in series, and a simple circuit with two lamps in parallel. Make sure that the students can appreciate the different arrangements. Relate the physical circuits to the circuit diagrams on the slide.



Slide 54

Small-group activity

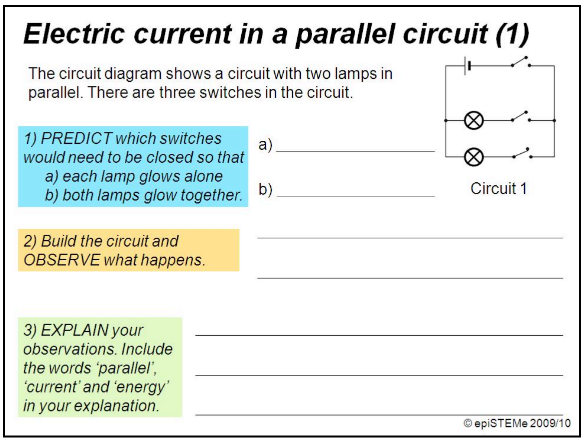
- Get the students to talk in pairs about the similarities and differences between the circuits.

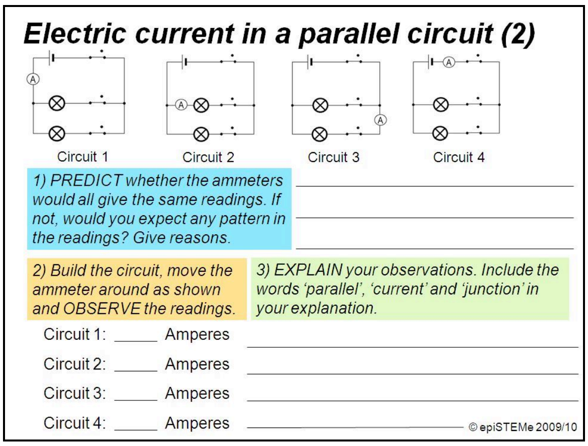
Whole-class activity

- Elicit responses from around the class. Accept a range of suggestions. Ask the students to comment on each other's suggestions. If students have different ideas, point out that this is an important part of science, as it provides ideas that can be tested.
- Now, close the switches in the circuits. In authoritative mode, demonstrate how two lamps in series are dimmer than a single lamp (when powered by a similar supply), but that two lamps in parallel can each be just as bright as a single lamp.
- Ask the students to suggest why this is, but do not yet provide a scientific explanation.

Small-group activity

- Get the students to work in groups on *Electric current in a parallel circuit (1)-(2)*. As usual, emphasise that groups should try to agree on their predictions (following the ground rules for productive talk) before building their circuits, and should try to agree on their explanations (see note on p.22: consider showing slide 85).

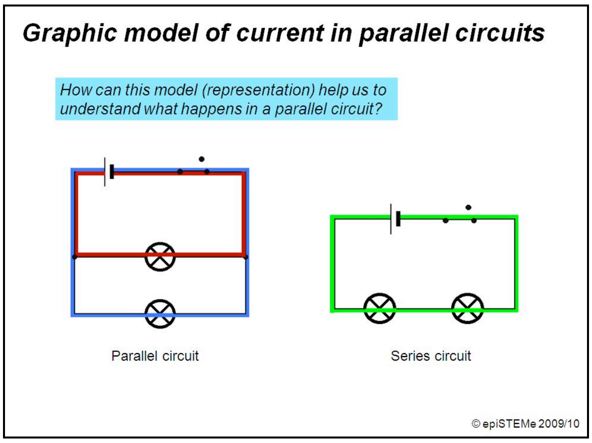


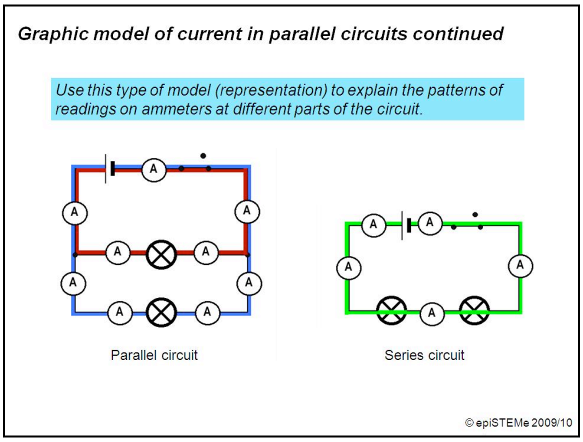


Slides 55-56

Whole-class activity

- Elicit the students' findings and thinking about what they have found. It is important that the students realise that the current through the branches adds up to the current from the cell, and you may wish to reinforce this by demonstrating with your demonstration circuit, or using simulation software projected on the screen/board.
- Show the students the *Graphic model of current in parallel circuits* and *Graphic model of current in parallel circuits continued*, which depict representations of the circuit diagrams overlaid with coloured lines.





Slides 57-58

- Tell the students that someone has suggested that this helps us think about current in a parallel circuit. Ask the students if they can see why this model (representation) might be useful.
- Ask the students if they can use this type of model (representation) to explain the patterns of readings on ammeters at different parts of the circuit. With some groups you may want to suggest some quantitative examples.

LESSON 6, PART 2: POTENTIAL DIFFERENCE AND PARALLEL CIRCUITS

Objectives

To show that p.d. across parallel branches is the same as that provided by the cell (which may be counter-intuitive). To provide an overview on the differences between series and parallel circuits.

Time

20-30 minutes depending upon class.

Resources

- Slide 59: p.d./voltage in a parallel circuit
- Slide 60: Electric current and p.d./voltage in a parallel circuit
- Slide 61: Electric current and p.d./voltage in a parallel circuit continued
- Slide 62: Graphic model of p.d./voltage in a parallel circuit
- Sufficient electrical kit for each student group to build circuits (each student group needs cell, 2 lamps, 3 switches, voltmeter, ammeter and connecting leads; each student group undertaking the extension activity with need an additional lamp and switch) – see slides 59-62
- Optional demonstration circuit and/or simulation software

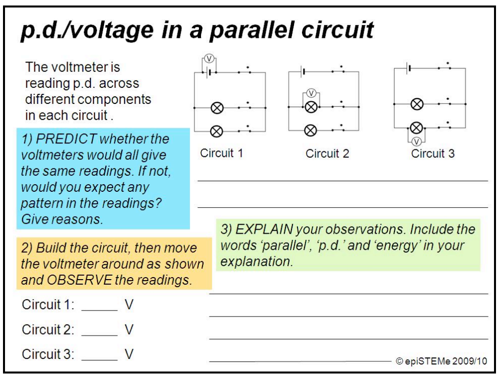
Activities

Whole-class activity

- Remind the students what they have already found out about current and p.d. in a series circuit, and ask them what difference they have discovered when measuring current in a parallel circuit (Lesson 6, Part 1).

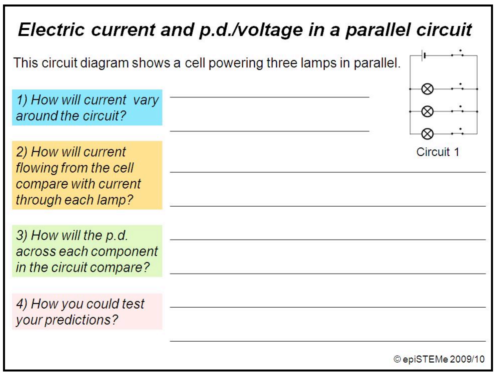
Small-group activity

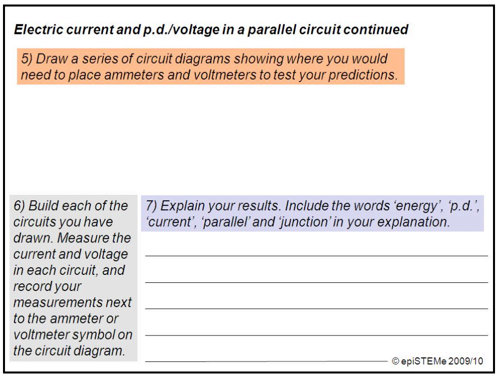
- Get the students to work in groups on *p.d./voltage in a parallel circuit*. Remind the students that scientists usually work by testing out their ideas, so they should make sure they have predictions to test before building the circuits. As usual, emphasise that groups should try to agree on their predictions (following the ground rules for productive talk), and should try to agree on their explanations (see note on p.22: consider showing slide 85).



Slide 59

- *Electric current and p.d./voltage in a parallel circuit* and *Electric current and p.d./voltage in a parallel circuit continued* may be used as extension work for students who would benefit from the challenge.

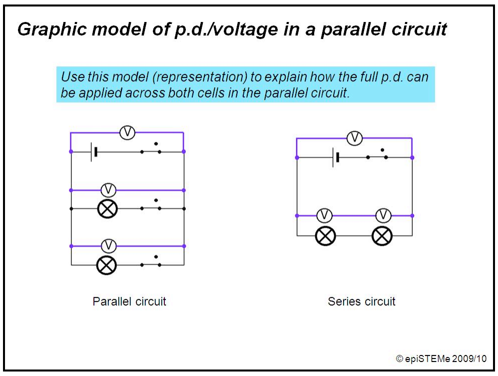




Slides 60-61

Whole-class activity

- Bring the class together for a plenary session, and ask the groups what they found out, and what they think was going on in the circuit. You may wish to use a demonstration circuit or simulation software to reinforce outcomes of the group practical work.
- The finding that the same p.d. may be found across both branches, and can fully power both lamps, may seem counterintuitive to the students (although of course, the cell is 'drained' quicker when energy is transferred to both lamps in this way).
- Display the slide *Graphic model of p.d./voltage in a parallel circuit* to help the students think about how the full p.d. can be applied across *both* cells in the parallel circuit. You may wish to ask pupils to think about the slide and discuss in their pairs whether this helps them understand p.d. in different types of circuits, and then to invite contributions. The idea that each branch is effectively connected across the full p.d. from the cell may be useful.



Slide 62

Note

- We do not normally connect voltmeters as shown in the series circuit (slide 63). If the two lamps (or the two meters) are not of the same specifications, then the meters will not show correctly how the p.d, is divided across the lamps (they will give the wrong ratio). That does not matter here, as the key point is that the p.d. is split in the series circuit, but not in the parallel circuit.

Lesson 7

Overview

Lesson 7 develops pupils' thinking about circuits in terms of the three models. The students are asked to explore how the models they have met can be used to think about parallel circuits.

Time

Approximately 60 minutes (some teaching groups will spend most if not all of the lesson on Part 1; but other classes may proceed quickly based on their learning from earlier lessons. Part 2 should be used as extension work where appropriate, at the teacher's discretion.

Aims

To allow pupils to revisit the models of electrical circuits, and to apply these models to parallel circuits.

Structure

The lesson is in two parts:

- *Part 1*: MODELLING PARALLEL CIRCUITS (25-45 minutes)
- *Part 2*: CHALLENGING CIRCUITS [EXTENSION] (40 minutes, where used)

Resources

Part 1: MODELLING PARALLEL CIRCUITS

- Slides 63-69

Part 2: CHALLENGING CIRCUITS (if used with class)

- Slides 72-76
- Sufficient electrical kit for each student group to build circuits (each group will need 2 cells, switch, 6 lamps and sufficient connecting leads).

LESSON 7, PART 1: MODELLING PARALLEL CIRCUITS

Objectives

To reinforce the differences between series and parallel circuits, and to provide the students with ways of thinking about what is going on in a parallel circuit. To consolidate, and extend, learning about the use of models in science.

Time

25-45 minutes depending upon group.

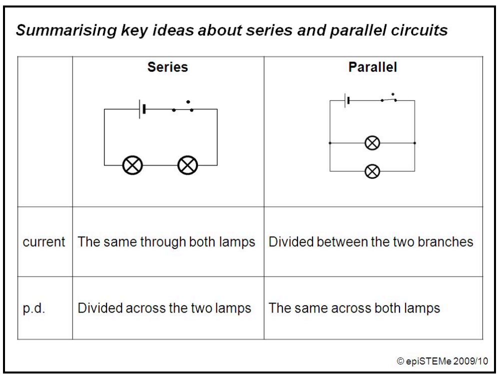
Resources

- Slide 63: Summarising key ideas about series and parallel circuits
- Slide 64: Role-play simulation in parallel circuits
- Slide 65: Rope-loop model in parallel circuits
- Slide 66: Supermarket delivery vans recap
- Slide 67: Comparing circuits to the supermarket delivery vans model (1)
- Slide 68: Comparing circuits to the supermarket delivery vans model (2)
- Slide 69: Comparing circuits to the supermarket delivery vans model (3)
- rope for rope loop model of circuits
- marbles (or other tokens) for role play

Activities

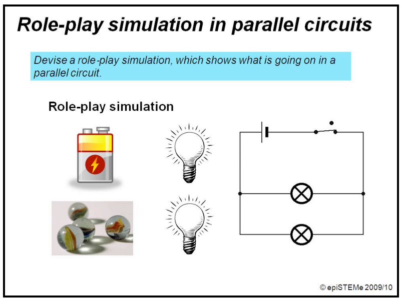
Whole-class activity

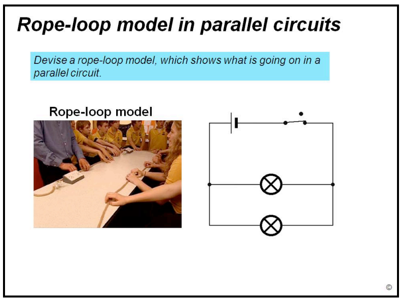
- Using *Summarising key ideas about series and parallel circuits*, review what has been discovered about the differences between series and parallel circuits.
- Ask the students if they can remember the ways used to model circuits in earlier lessons (the supermarket delivery vans model, the rope-loop model, the role-play simulation).

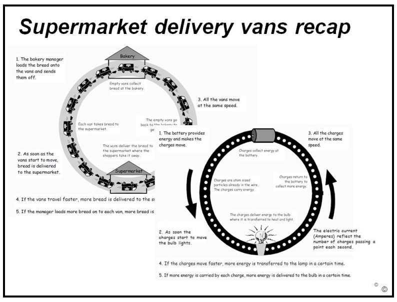


Slide 63

- Working with the students, see if the class can devise a role-play that would show what is going on in a parallel circuit (*Role-play simulation in parallel circuits*). The students need to work out how to have current that divides at one junction and then recombines at another junction. Let the students suggest how this model can simulate how p.d. is constant across the different branches. (This could be students moving just as fast in each branch as if it was a single lamp circuit, whereas they would slow in a circuit with lamps in series. However, it does not matter if the students cannot suggest anything, as this should then be considered a possible limitation of this model.) Point out to students that the type of thinking needed to plan the role play ('What could be going on here?', 'How might that work?', 'So what would happen if…') is an important part of the work of scientists. (Einstein was very famous for his thought experiments, and this type of thinking ideas through is key to much scientific work.)
- Move on to demonstrate the rope-loop model for a parallel circuit (*Rope-loop model in parallel circuits*). Let the students suggest how to do this. (This would need two loops, but again work with what the students suggest, explore their ideas, and lead them to comment on how well the model works – its strengths and weaknesses.)
- As a preparation for the following group work activity, elicit from the students the key components of the supermarket delivery vans.



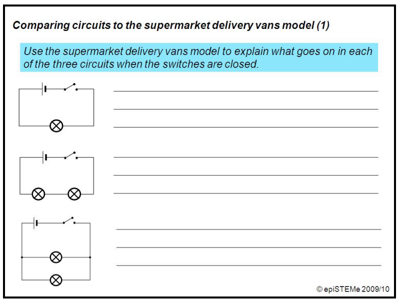


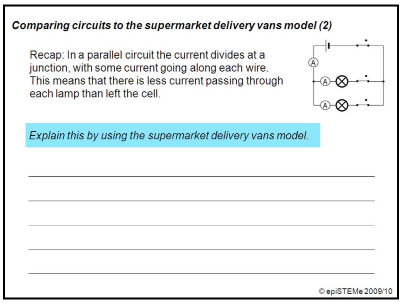


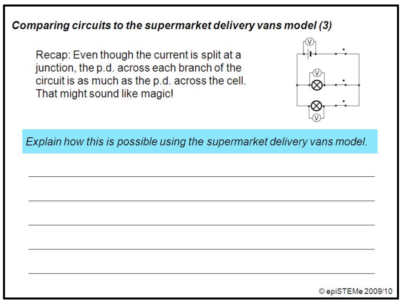
Slides 64-66

Small-group activity

- Get the students to work in groups on *Comparing circuits to the supermarket delivery vans model (1)-(3)*. Remind the students to discuss each answer before writing out their group's answer.







Slides 67-69

- *Comparing circuits to the supermarket delivery vans model (1)* asks the students to consider the difference between a simple (one lamp) circuit, a series circuit (i.e. where the vans must deliver to two supermarkets, and take some produce to each) and a parallel circuit (i.e. where different vans go to deliver to two different supermarkets).
- *Comparing circuits to the supermarket delivery vans model (2)-(3)* reinforces the dividing of current, and asks the students to think about how the p.d. can be the same across both branches (e.g. having twice as many people loading the vans in the warehouse). With some classes, you may prefer to work through this activity in whole class mode. If appropriate, use this activity as a group exercise to differentiate between groups in the class.

Whole-class activity

- Bring the class together into plenary mode, and explore the ideas from different groups. Conclude by highlighting how models can have strengths and weaknesses, and that even useful models have limitations. Explain that scientific models have a ‘range of application’, beyond which they do not work well.

LESSON 7, PART 2: CHALLENGING CIRCUITS [EXTENSION]

Objectives

To provide challenging examples to stretch more able student. (This material has quite a high demand in terms of reading and circuit building.) To reinforce earlier learning, and opportunities to think about, describe, model and explain more complex circuits.

Time

30-40 minutes, depending upon the group.

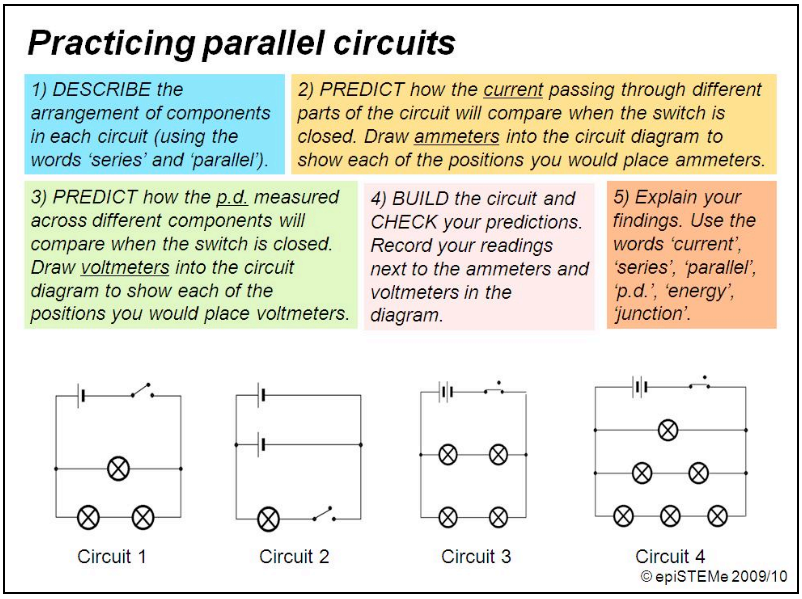
Resources

- Slide 72: Practicing parallel circuits
- Slide 73: Supermarket delivery vans model in complex parallel circuits (1)
- Slide 74: Supermarket delivery vans model in complex parallel circuits (2)
- Slide 75: Supermarket delivery vans model in complex parallel circuits (3)
- Slide 76: Supermarket delivery vans model in complex parallel circuits (4)
- Sufficient electrical kit for each student group to build circuits (each group will need 2 cells, switch, 6 lamps and sufficient connecting leads) – see slide 72
- Optional use of a demonstration circuit (as per student circuit) or simulation software

Activities

Small-group activity

- Get the students to work in their groups on *Practicing parallel circuits*. Remind the students to discuss questions in their groups, with group members explaining their ideas and seeking to agree, before moving on (see note on p.22: consider showing slide 85).



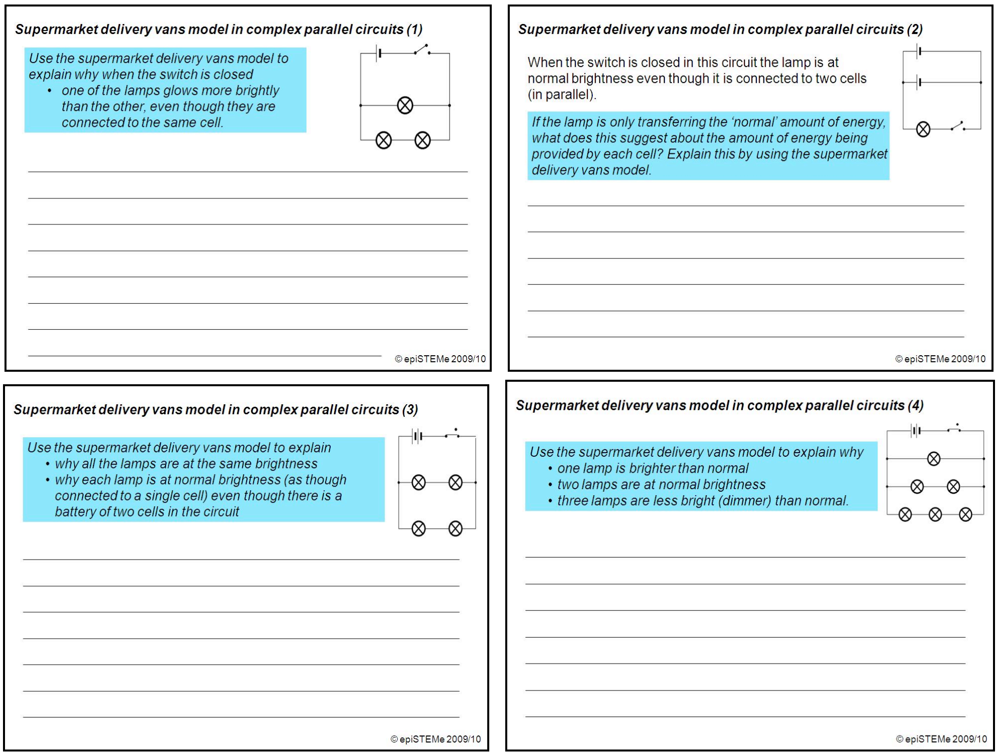
Slide 72

Whole-class activity

- Debrief in whole class. Ask students for their findings but be prepared to present (in authoritative mode) the canonical outcome. (The single lamp is brighter in circuit 1; the lamp is at normal brightness in circuit 2; the lamps are at normal brightness in circuit 3 (as the p.d. from two cells is divided across two lamps in each parallel branch); the single lamp on a parallel branch is brighter than normal, the two lamps in parallel are at normal brightness, the three lamps in parallel are dimmer than normal in circuit 4).
- You may wish to use a demonstration circuit or simulation software to reinforce findings or settle disputes over observations.

Small-group activity

- Get the students to work in their groups on *Supermarket delivery vans model in complex parallel circuits (1)-(4)*, which asks the students to explain more complex circuits in terms of the supermarket van model.



Slides 73-76

Whole-class activity

- Debrief in whole class mode.

Note

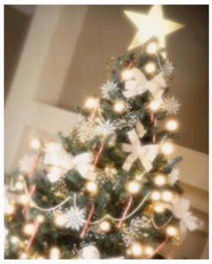
- This material is provided for differentiation purposes, to challenge faster and higher achieving students; and for those teachers with time to extend circuit work. However, this material would provide valuable opportunities to reinforce key learning for all groups. So, if the students are clearly enjoying this topic, and time is available, it may be worthwhile including this material for the whole class - perhaps in a more directly supported form - in mixed ability or average ability groups.

LESSON 7, HOMEWORK (OPTIONAL)

Christmas tree lights

Mr Holiday had bought two Christmas trees – one for the lounge and one for the dining room. One of the trees had a set of lights connected in series. The other tree also had a set of lights, but connected in parallel.

By Boxing Day, one of the lamps on each tree had broken. However, all the lights had gone out on one of the trees.



Explain why all the lights had gone out on one of the trees but not on the other. In your explanation, use the words 'current', 'switch', 'series', 'conduct', 'parallel'.

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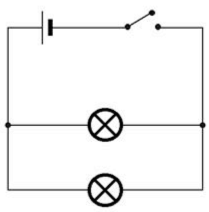
Slide 70

Eddie/Edwina the electron in a parallel circuit

Imagine you are Eddie/Edwina the electron, who 'lives' in the circuit shown here.



Describe a day in the 'life' of E.

Remember that when E reaches a junction, E has to go one way or another. How does E decide?

Hint: Remember E and his/her friends move very fast, and there are LOTS of them all around the circuit.

Slide 71

Lesson 8

Overview

Lesson 8 draws upon student experience of the three models of electrical circuits (supermarket delivery vans, rope, role-play) to evaluate and critique these models – to support learning about the role of models in science, as well as reinforcing their thinking about circuits. As throughout the module, electrical circuits are used as a context for learning about the role of models in science, and the three models are used to provide a basis for students to interrogate what they observe in different electrical circuits, and so stimulate deep thinking about circuits.

Time

Approximately 55 minutes.

Aims

To allow students to review, and critically evaluate, the models (analogies) that have been used to make sense of circuits during the module.

Structure

The lesson is in two parts:

- *Part 1*: EVALUATING MODELS OF CIRCUITS (35-40 minutes)
- *Part 2*: COMPARING CIRCUITS (15 minutes)

Resources

Part 1: EVALUATING MODELS OF CIRCUITS

- Slides 77-81

Part 2: COMPARING CIRCUITS

- Slides 82-83

LESSON 8, PART 1: EVALUATING MODELS OF CIRCUITS

Objectives

To explore the use and limits of models, and show how different models have different strengths and weaknesses (and perhaps 'work' better for different people?)

Time

35-40 minutes, depending upon the group.

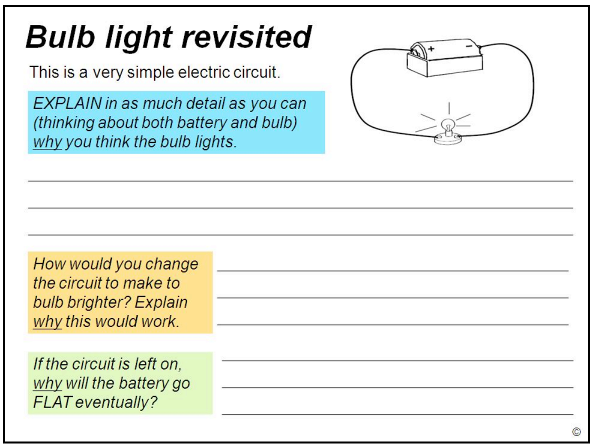
Resources

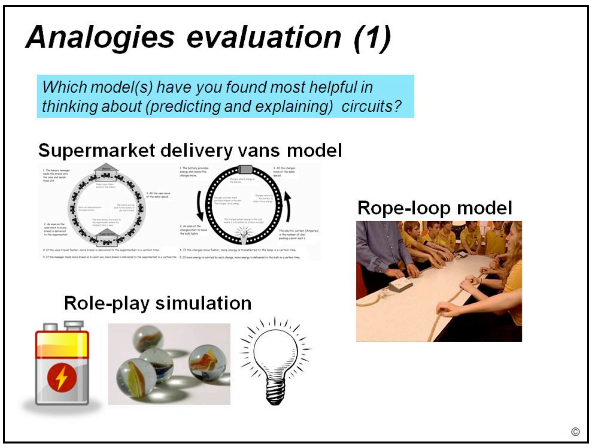
- Slide 77: Bulb light revisited (and student responses from Lesson 1, Part 3)
- Slide 78: Analogies evaluation (1)
- Slide 79: Analogies evaluation (2)
- Slide 80: Analogies evaluation (3)
- Slide 81: Analogies evaluation (4)

Activities

Whole-class activity

- This may be a good time to revisit the students' initial ideas at the start of the module, so they can consider if their ideas have changed
- Using *Bulb light revisited*, ask the students to look at what they wrote on the activity *Bulb light* in Lesson 1, part 3.
- In whole-class mode, invite the students to reflect upon whether they have changed their thinking, and if so to explain how (and if they can, why)
- Remind the students of the three models they have used to think about circuits during the module [*Analogies evaluation (1)*].

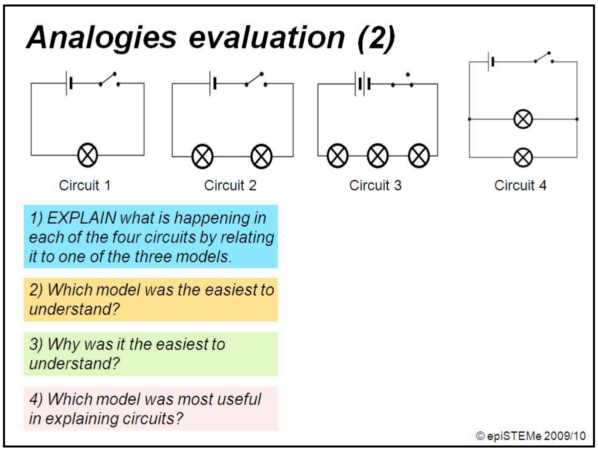


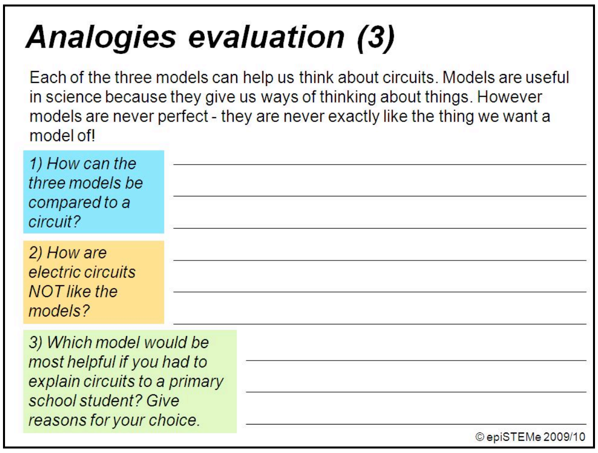


Slides 77-78

Small-group activity

- Get the students to work in their groups on *Analogies evaluation (2)* to consider which model(s) they found most helpful in thinking about (predicting and explaining) circuits.





Slides 79-80

Whole-class activity

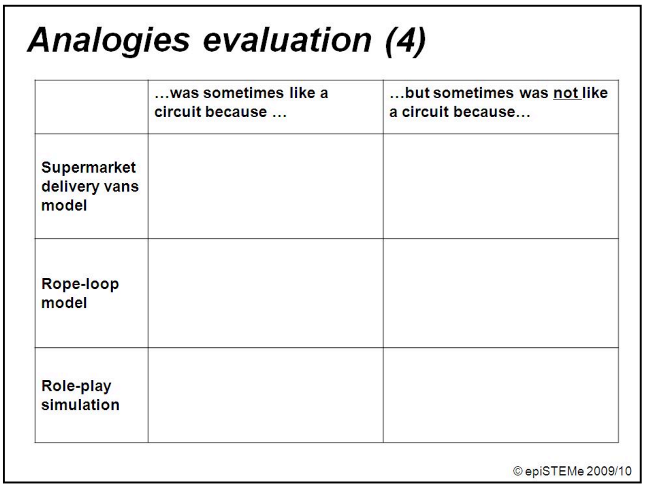
- In a plenary session, review the ideas of different groups. Did everyone in the class agree on their answers? If not, lead a discussion of why different students found different models easier to understand/more helpful.
- Where possible relate their comments back to the features of circuits explored in the module: use the models/analogies to emphasize aspects of the scientific model.

Small-group activity or Whole-class activity

- *Analogies evaluation (3)* asks for extended writing. This can be set as a group task as extension work for those finishing *Analogies evaluation (2)* quickly, or in classes working at a higher level. With some classes it may seem more appropriate to work through these questions as a class, and incorporate these points within the plenary from activity *Analogies evaluation (2)*.

Whole-class activity

- Summarise key ideas from the class, e.g. in a simple table [*Analogies evaluation (4)*]
- Draw out explicit points about positive and negative aspects of analogies.
- Emphasise that sometimes scientists find it useful to work with several different models, each having its own strengths and limitations.



Slide 81

LESSON 8, PART 2: COMPARING CIRCUITS

Objectives

To give students opportunities to rehearse and review what they have learned from the module.

Time

15 minutes.

Resources

- Slide 82: Circuits - odd one out
- Slide 83: Circuits - most alike

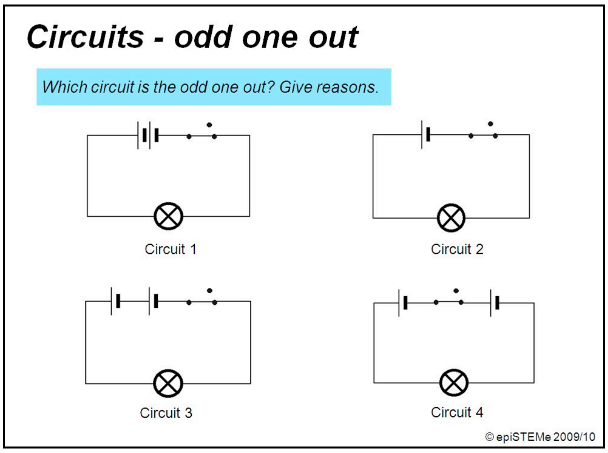
Activities

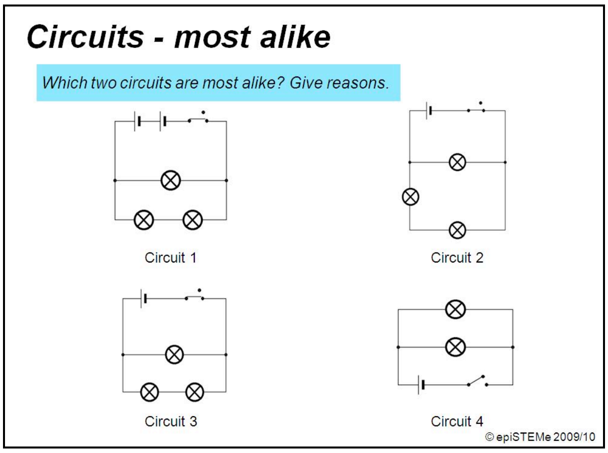
Small-group activity

- Project the *Circuits - odd one out* slide and give the students 2 minutes to consider the question in their pairs. The groups should be encouraged to consider these questions using the three models.

Whole-class activity

- Let the students report back and discuss within the whole class. Invite suggestions from several students. Praise the students if they use technical language (current, energy, p.d., parallel, series, etc.). Accept any different suggestions, asking other students to comment on them, before closing down discussion. [Three circuits are effectively the same, but one has only one cell and is, from a scientific perspective, the odd one out].





Slides 82-83

Small-group activity

- Project the *Circuits - most alike* slide and follow the same routine.
- It is important that the students realise that it is the arrangement of circuit components that is important, which makes 2 and 3 the best match (even if 1 and 3 may look more similar).

Lesson 9

Overview
Lesson 9 provides students with an activity to focus their minds on the work they have done on electrical circuits.

Time
Approximately 20 minutes.

Aims
To evaluate student learning experiences, and progression in student learning during the module.

Structure
The lesson is in three parts:
Part 1: CIRCUIT DOMINOES (15-20 minutes)

Resources
Part 1: CIRCUIT DOMINOES

- Slide 84
- Master copies of dominos in plastic folder: make copies for the students beforehand

LESSON 9, PART 1: CIRCUIT DOMINOES

Objectives

To encourage the students to discriminate between significant features of circuits/circuit diagrams.

Time

15-20 minutes (depending on group, and teacher view of how engaged the students are).

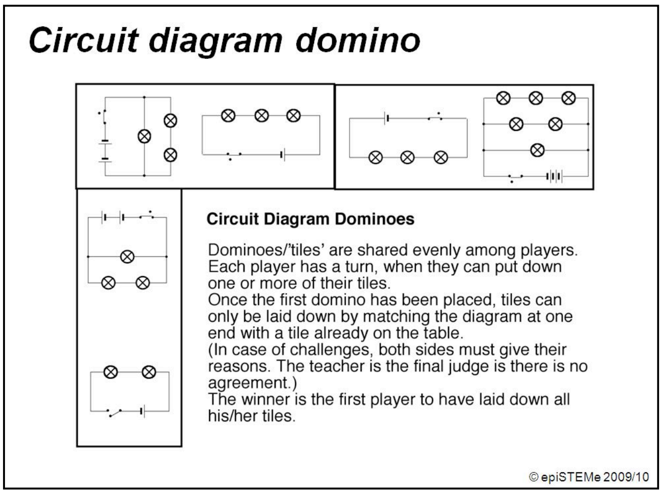
Resources

- Slide 84: Circuit diagram domino
- Master copies of dominos in plastic folder: make copies for the students beforehand

Activities

Small-group activity

- This should be an enjoyable revision activity.
- Some students will have played dominoes before: other may need to have the game explained.
- The students play in groups of 4-5 players. Dominoes can only be laid down if they match (at one end) an unused end of the domino complex being formed. If students disagree on whether there is a match, they need do discuss the reasons for their views, and try to agree. (You could set a rule that they have to give their reasons using scientific language.)



Slide 84

Note

- There are three versions of the domino task (to allow differentiation between classes, or between groups within mixed ability classes):
  1) only closed circuits, and no measuring instruments (simplest *);
  2) open and closed circuits mixed, but no measuring instruments (more difficult **);
  3) only closed circuits, but with or without meters (most difficult ***).
- Circuits can be considered the same whether switches are open, or not, and whether there are meters, or not; but the harder versions require the students to make discriminations despite the 'noisier' data.

APPENDIX: epiSTEMe

The epiSTEMe project [Effecting Principled Improvement in STEM Education] is part of a national programme of research that aims to strengthen understanding of ways to increase young people's achievement in physical science and mathematics, and their participation in courses in these areas. Drawing on relevant theory and earlier research, the epiSTEMe project has developed a principled model of curriculum and pedagogy designed to enhance engagement and learning during a particularly influential phase in young people's development: the first year of secondary education. The module on 'Electricity: electric circuits' is one of four topic-specific modules that have been developed to operationalise that model and support its classroom implementation.

The teaching model

The epiSTEMe teaching model builds on current thinking and promising exemplars that have been extensively researched. These suggest that students' learning and engagement can be enhanced through classroom activity organised around carefully crafted problem situations designed to develop key disciplinary ideas. These situations are posed in ways that appeal to students' wider life experience, and draw them more deeply into mathematical and scientific thinking. Such an approach is intended not just to help students master challenging new ways of thinking, but also to help them develop a more positive identity in relation to mathematics and science.

An important feature of the teaching model is the way in which it makes explicit links between mathematics and science. Within mathematics modules, the primary rationale for this is that science represents a major area where an unusually wide range of mathematics is applied, often for a variety of purposes. Within science modules, the primary rationale is that understanding of scientific ideas is deepened by moving from expressing them in qualitative terms to representing them mathematically.

The teaching model also emphasises the contribution of dialogic processes in which students are encouraged to consider and debate different ways of reasoning about situations. These dialogic processes are designed to take place in the course of joint activity and collective reflection at two levels of classroom activity: student-led (and teacher-supported) collaborative activity within small groups, and teacher-led (and student-interactive) whole class activity. Because of the importance of developing dialogic processes that support effective learning, these processes are the focus of a separate introductory module, which is additional to the four topic-specific modules.

The design of the topic-specific modules

The function of all four topic-specific modules is to provide examples of concrete teaching sequences that incorporate classroom tasks that reflect the teaching model. The tasks will, in particular, support dialogic processes and will be supported by these processes.

First, each module has been designed to cover those aspects of the topic suitable for the start of the Key Stage 3 curriculum, and to do so in a way that is suited to students across a wide range of achievement levels. Taking account of available theory and research on the development of students' thinking in the topic, the module 'fills out' the official prescriptions in ways intended to build strong conceptual foundations for the topic. This includes providing means of deconstructing common misconceptions related to the topic.

In this way, the modules take account of students' informal knowledge and thinking related to a topic. They also make connections with widely shared student experiences relevant to a topic. Equally, with a view to helping students understand how mathematics and science play a part in their wider and future lives, the modules try to bring out the human interest, social relevance, and scientific application of topics.

Finally, while the modules place a strong emphasis on exploratory dialogic talk, they also make provision for later codification and consolidation of key ideas, and build in individual checks on student understanding that can be used to provide developmental feedback.

Key references to support teachers

IoP (2006) Supporting Physics Teaching (11-14) CD-ROM. London: Institute of Physics. An essential resource for any non-specialist teaching physics who feels the need for support with subject knowledge and specialist pedagogy. These materials were originally issued as a set of CDs, but may now be downloaded from http://www.talkphysics.org/ .

The National Strategy (2008) *Explaining how electric circuits work* - Ref: 00094-2008DVD-EN (http://nationalstrategies.standards.dcsf.gov.uk/downloader/5617eb367b754cd48d7237f82085ffc5.pdf)

'Teaching Science for Understanding: Electric Circuits' by Hind, et al (undated). Centre for Studies in Science and Mathematics Education, The University of Leeds. (http://www.education.leeds.ac.uk/research/cssme/ElecCircuitsScheme.pdf)

One example of useful simulation software is **PhET** Website Simulations:
http://phet.colorado.edu/simulations/sims.php?sim=Circuit_Construction_Kit_DC_Only

Easy access via download link:

http://phet.colorado.edu/admin/get-run-offline.php?sim_id=84&locale=en

Other useful sites

http://www.teachers.tv/video/18955

http://www.msnucleus.org/membership/html/k-6/as/index.html

http://www.msnucleus.org/membership/slideshows/electricity.html

http://www.bbc.co.uk/schools/ks3bitesize/science/physics/electricity_4.shtml

http://www.msnucleus.org/membership/html/k-6/as/technology/4/ast4_3a.html