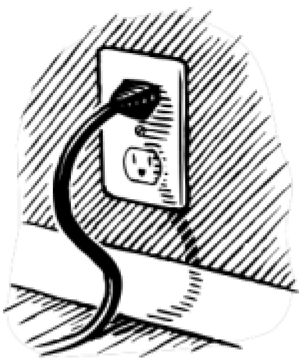
Super Sucker
Designing a machine to clean up litter

Electrical engineering
Electricity
Unit for pupils from 11-12 years



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Introduction

This is one of ten ENGINEER primary school units developed to support science learning within the context of a wide range of engineering design challenges. Based on the successful Boston Museum of Science *Engineering is Elementary* model of inquiry-based learning, each unit features a different science area and engineering field and requires only inexpensive materials in order to support pupil-led science exploration and problem-solving design. The units have been developed to appeal to a wide range of pupils and to challenge stereotypes of engineering and engineers and so enhance both boys' *and* girls' participation in science, technology and engineering.

Our pedagogic approach

Central to each unit is the engineering design cycle: ask, imagine, plan, create, improve. Emphasizing the cycle helps teachers to foster pupils' questioning and creativity, and gives space for pupils to develop their problem-solving skills including testing alternative options, interpreting results and evaluating their solutions. Tasks and challenges have been designed to be as open-ended as possible, and to avoid 'right answers'; in particular, the unit developers have aimed to avoid competition which may alienate some pupils, while retaining the motivation of wanting to solve a problem. An important goal of all of the units is to maximise opportunities for group work and to support pupils in learning to work together and communicate their ideas effectively. Students need to discuss their ideas as they explore a new problem, work out what they need to know and share their findings, design solutions, and then improvements.

How the units are organised

Each unit begins with Lesson 0, a general preparatory lesson which is common to all ten units. Teachers choosing to use more than one unit will want to start with this lesson the first time they use the units and begin at Lesson 1 in subsequent units. Lesson 1 introduces a story context or problem which drives what happens next: Lesson 2 focuses on what exploring the science that the pupils need to solve the problem, while in Lesson 3 they design and build their design solution. Finally, Lesson 4 is an opportunity to evaluate, present, and discuss what they have done.
Each unit is, however, unique, and some units are more demanding in terms of science understanding and the length of time required for the unit varies. Likely timings and age targets are indicated in each unit overview. Units have been designed to be flexible, however – teachers can choose which activities they want to include, and there are options for differentiating activities to cater for a range of abilities.

Teacher support

Each unit guide has been written to provide appropriate science, technical and pedagogic support for teachers with a wide range of experience and expertise. Each lesson includes suggestions and tips for supporting inquiry-based learning, classroom organisation and preparation. Science and making activities are illustrated with photographs. Science pedagogy notes in the Appendix explain and discuss the science involved in the unit and how to support understanding of the central concepts for pupils in the age range. Worksheets which can be copied and answer keys are also provided.

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Overview of the unit

Duration: 4 hours 45 minutes plus 35 minutes of extension activities

Target group: 11-12 year old pupils

Description: by participating in the challenge "Let's clean things up – designing a vacuum cleaner" pupils will learn about electricity and electrical engineering.

Science curriculum: this unit relates to the science curriculum for electricity.

Engineering field: this unit introduces the field of electrical engineering.

Objectives: in this unit pupils will learn

- that engineers use a series of steps, called the Engineering Design Process , to design solutions to problems;
- to identify problems and needs that can be solved by means of technology, and to plan solutions by using the engineering design process;
- to understand electric circuits and the science which underlies them ;
- how to use batteries, small motors and fans;
- to design and create a small vacuum cleaner by understanding how it works.

The lessons in this unit:
A **Preparatory lesson** aims to raise awareness of how engineering contributes to our daily lives in ways that are not always obvious.
Lesson 1 introduces the engineering problem, its context and the engineering process.
In Lesson 2, the 'ask' element of the engineering process leads to an investigation of electricity.
Lesson 3 involves the pupils in applying the engineering design process to meet the challenge. The challenge is to design small vacuum cleaners.
In Lesson 4, it's time to evaluate the process of creating the vacuum cleaners. This is also the moment for pupils to show whether they were able to meet all the criteria and to talk about how they made improvements.

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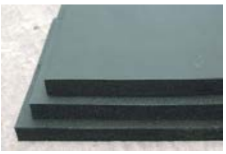
Resources

List of all the materials and quantities needed for 30 pupils.

Material	**Total amount**	**Lesson 0**	**Lesson 1**	**Lesson 2**	**Lesson 3**	**Lesson 4**
Hairdryer 	1-6			X		
Small motors 1,5-3V 	15-30			X	X	
Batteries 4,5V or 3x1,5 V  	15-30			X	X	
3 x AA Battery Box 	15-30			X	X	
Solid Core Wire 	1			X	X	
Plastic bottles from 0,5l-2l 	15				X	
Paper fasteners 	1 box			(X)	X	
Paper clips 	1 box			(X)	X	

Pieces of card board 10x10 cm	15			(X)	X	
Side Cutting Pliers 	2-3			(X)	X	
Wire strippers 	2-3			(X)	X	
Foam rubber 					X	
Rubber band (broad) 	10			X	X	
Debris from a hole puncher 						
Saw	1				X	
Gluepistol 	1				X	
Sticky tape	1 rule				X	
Scissors	6				X	
Lollipop sticks 	10				X	
Paper A4	50			X	X	

Lesson 0 – Engineering an envelope
What is engineering?

Duration: teachers can choose how long to spend on this lesson depending on how much experience pupils already have. The introduction, main activities and conclusion will take up to 40 minutes; additional extension work can add a further 10-30 minutes.

Objectives, in this lesson pupils will learn that:

- engineers design solutions to problems using a range of technologies;
- technologies that are appropriate for a particular problem depend on the context and materials available;
- made objects have been engineered to solve problems;
- engineers can be men or women.

Resources (for 30 pupils)

- 8 'post-it' notes packs
- 8 sets of at least 5 different envelope types
- 8 sets of at least 5 different objects
- 8 sets of packaging examples for optional extension work
- Card, paper, glue, scissors for optional extension work

Preparation

- Collect together a range of different envelopes and packages
- Print copies of worksheet 1 if using
- Collect pictures for introductory activity

Working method

- Small groups
- Whole class discussion

Context and background

This lesson is the same in all units and is intended to encourage thinking about what technology is and to challenge stereotypes about engineers (particularly those associated with gender) and engineering.

It aims to develop the understanding that objects in the made world are designed for a purpose and that technology in its broadest sense refers to any object, system or process that has been designed and modified to address a particular problem or need.

Pupils can think about this by discussing what problem the technology of a particular artefact (in this case an envelope) is intended to solve. In this lesson, they discuss the range of technologies that are used to engineer an envelope for a particular intended purpose.

The lesson is also intended to avoid value judgments of ' high tech' versus 'low tech' and to encourage pupils to appreciate that it is appropriate technology in a particular context that is important: the range of available materials will determine the technology that the engineer applies to solving the problem.

0.1 Introduction - 10 minutes - small group and whole class discussion

Divide the class into groups of 4 and provide a packet of 'post-its' for each group. Ask the groups to discuss all the things they associate with the terms 'engineering' and 'technology'. Ensure that, as part of the discussion, each individual within the group puts at least one idea on a 'post it'.

Invite each group to place their 'post its' on to a master display sheet and briefly explain their choices to the rest of the class. Keep the whole class list for review at the end of the lesson.

Additional support for discussion

This part of the lesson can be extended by providing pictures of stereotypical and unusual examples of engineering and asking pupils to group the pictures into those that they associate with engineering and those that they do not. You could use Worksheet 1 for this activity, or use the pictures there as a whole class display. Ask pupils to work in pairs to decide which of the pictures they think are related to engineering and to give their reasons why they think that some are and some are not. Each pair of pupils could share their ideas with another pair and discuss similarities and differences in ideas. You could use these ideas as a basis for a whole class discussion; encourage pupils to open up their thinking about what counts as engineering and who could be involved in it.

0.2 Activity 1 What is an envelope? - 5 minutes, small groups

Organise pupils into small groups to discuss what an envelope is and what counts as an envelope. To help discussion, provide a range of examples which cover and/or protect objects or materials for particular purposes (as in the pictures).

An important part of this activity is to encourage pupils to notice that there are many interpretations of the idea of an envelope. In the pictures there are some examples that might challenge their idea of an envelope: they include a broader interpretation of what an envelope is as something that 'houses', 'protects', 'holds in place', 'covers', 'hides' or even 'reveals' a range of different objects.

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0.3 Activity 2 Matching envelopes to objects - 15 minutes - small groups and whole class discussion

Divide the class into groups of 4 and provide a range of 'envelopes' and objects that could go in them. Ask the pupils to select which envelopes would be most suitable for the objects and to explain why.

The objects could include: a pair of spectacles; a certificate or photograph that must not be bent; a delicate piece of jewellery; a returnable DVD; a set of confidential papers; a pair of scissors. The range of objects and envelopes can be varied according to context and what you have available.

The following questions can help guide the discussion:

– What material is the envelope made from?
– What fixings and fastenings are used in the envelope?
– What range or types of objects could the envelope be used for?
– What other materials it could be made from?

Each group should report their ideas back to the class.

There is an opportunity here for the teacher to lead the discussion and talk about the various technologies used in each engineered envelope including the types of structures, fixings and fastenings used (e.g. reusable or permanent fixings; reinforcement areas; internal and external materials selected; how edges are sealed.)
This is an evaluative activity and could be related back to the engineering design process: discussion could include thinking about the process that engineers need to be involved in when making something to solve a particular problem.

0.4 Extension work - optional - 10-30 minutes - small groups

1. Present pupils with a range of envelopes and ask them to evaluate their design in terms of their fitness for purpose (see picture).

Envelopes could be compared in terms of the types of fastenings and reinforcements used, and the mix of different materials used (e.g. bubble wrap, absorbency, strength- i.e. resistance to tearing).
This activity could be extended to looking at different types of packaging in relation to net folds and how these are used to reduce (or eliminate) the need for adhesives in the manufacturing process. The following 3 pictures demonstrate packaging that does not use any form of adhesive; the making involves only one type of material using cuts and folds for fastenings.

2. Organise pupils into small groups to design and/or make an envelope in order to deliver a particular chosen object. Groups will need to draw on their understanding of materials and the design making process to produce a range of alternative designs. These could then be evaluated in whole class discussion.

0.5 Conclusion - 10 minutes - whole class discussion

Lead a plenary discussion drawing on the original class 'post its' (and where appropriate their groupings of the 'engineering' photographs), reminding the pupils of how their original thinking might now have changed. Ask pupils to reflect on what an engineer does and what technology is.

- Emphasise that most things we use are made for a purpose and that engineers use a range of skills in finding solutions to problems.
- This involves thinking about solutions to solve problems; some of these work and some are less successful – the engineering design process includes evaluation and improvement.
- It is not 'high' tech or 'low' tech but *appropriate* technology that matters - engineers need to consider their context and resources.
- There are many types of engineering, and many different types of people from across the world, and both men and women, are engineers.

There might be a range of equally acceptable definitions for the terms 'engineer' and 'technology'; these terms are often used interchangeably, e.g. engineering could be considered as the use of technology for problem solving. In talking about the relationship between *engineering, science and technology, pupils can be encouraged to think about how engineers, in the process of making objects to solve problems, use a range of technologies (including fixings and fastenings, various types of materials and different components in a range of systems) and a range of science understandings. This is an opportunity to open up discussion about how things are made and by who, and what is involved in the process of thinking about solutions to problems.*

0.6 Learning outcomes - for optional assessment

At the end of this lesson pupils should be able to**:**

- Recognise how a range of systems, mechanisms, structures, fixings and fastenings are used in artefacts in different ways to provide a range of solutions to solve problems
- Understand that appropriate technology is often dependent on the context and materials available
- Recognise that engineers use a wide range of skills in developing solutions to problems
- Recognise that many different types of people with different interests and skills can be engineers

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Lesson 1 – What is the engineering problem?
Finding out about the challenge

Duration: 55 minutes

Objectives: in this lesson the pupils will learn
- the principal functions of the vacuum cleaner as an example of electrical engineering;
- how the engineering design process structures a design challenge;
- that electricity is a form of energy.

Resources (for 30 pupils)
- white board
- the design challenge story (see appendix)

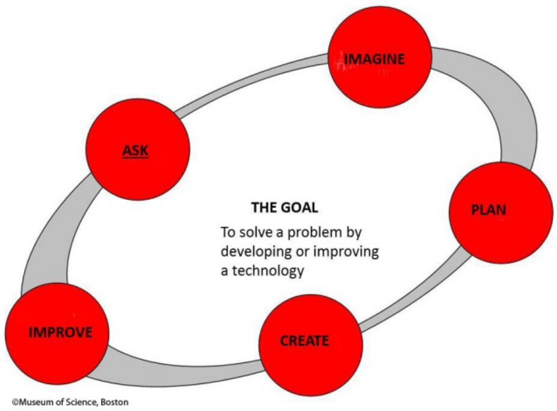
Preparation
- Read about electrical engineering and the EDP
- Make copies of Worksheet 1

Working methods
- Individually and in groups

Key ideas in this lesson
- What engineers do and how they work.
- The design challenge context is introduced

Context and background

The challenge, the context and the design cycle are introduced. The pupils consider what knowledge they need to know in order to meet the challenge.



1.1 Introductory activity - whole class - 10 minutes

Tell the pupils that this unit introduces the field of electrical engineering.
Ask the pupils to name electric items in the classroom, or in their homes. Who do they think has developed them? Discuss the role that electricity and electrical items have in everyday life. What would a day be like without electricity?

Electrical engineering is based on ideas in physics. It is about many things, from the smallest electronic components in computers and mobile phones to the generation and use of our electricity supply system. Electro-technology includes telecommunications, electronics, radio engineering and electrical engineering. Electricity can be used to transfer energy, i.e. the use of electricity as an energy carrier, such as the power grid or electric motors.

1.2 The engineering challenge - whole class - 10 minutes

Read the engineering challenge story in the Appendix. Ask pupils if they think they could solve the problem. What do they need to know to solve this problem?
Write the problem on the white board. The problem is to "design a small vacuum cleaner".
Tell the pupils that they now are going to work in the same way as engineers.

Tip - Information for the teacher. The name "vacuum cleaner" is a bit of a giveaway when it comes to understanding how the machine works: vacuum cleaners work by suction. (In fact, "suction cleaner" would be a better name than vacuum cleaner, because there's no actual vacuum involved). The mechanical / electrical part is really a strong motor that blows air, usually out the top or back of the cleaner, creating a suction force at the bottom (where the dust is pulled inside). All vacuum cleaners work on the same principle....if you attach a motor that blows air (say a fan) out of one end of an object that has an opening at the other end, it will work in the same way and cause air to flow first into the object, then out through the fan.

Tip - If you want to know more about how vacuum cleaners work you can look at these webpages:
http://home.howstuffworks.com/vacuum-cleaner.htm
http://www.explainthatstuff.com/vacuumcleaner.html

1.3 The "ASK" phase of the EDP - small groups - 20 minutes

Step 1 "ASK" in the EDP. **Use worksheet 1, lesson 1 (EDP plan)**. Emphasise that all engineering challenges begin with questions. Start by asking what do the pupils need to know to design and build a small vacuum cleaner? Have the pupils work in small groups of4-5. Try to ensure that the groups are gender and attainment mixed. Let them discuss for around 5 minutes what they need to know to solve the problem. Ask pupils to write all the questions from their group on worksheet 1 on the page with the ASK phase. Write the questions from all the groups on the board.
Questions that might come up:

- How can we make a suction force?
- Can we look at a real vacuum cleaner?
- What materials can we use?

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- What parts are needed?
- What kind of dust will our vacuum cleaner be able to pick up?
- What are the criteria for success?
- How can we make a fan?
- How big should the cleaner be?
- Should it have wheels?
- How can we make a switch?

1.4 Conclusion - plenary - 10 minutes

Summarise the learning objectives. Discuss with the pupils: what have you learned about electrical engineering? Can you describe the different stages in the design process? Have you learned what a vacuum cleaner does?

Tell the pupils that in the next lesson they will begin to answer their questions and that they will be introduced to the things that they need to know in order to solve the problem of designing and constructing a vacuum cleaner. Ask pupils to bring hairdryers for the next lesson. They will only be looking at the hairdryers, they will not be taking them apart

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Lesson 2 – What do we need to know?
Finding out about electricity

Duration: 60 minutes (80 minutes with extension activity)

Objectives: in this lesson the pupils will learn
- about electric circuits and the direction of current;
- how to use batteries, small motors and fans;
- about the different parts of a hairdryer as a prelude to designing a vacuum cleaner.

Resources (for 30 pupils)
- 1-6 Hairdryers
- 30 small motors 1,5-3V
- 30 Batteries 4,5V or 3x1,5 V
- Paper
- Cardboard (optional)
- Paper fasteners (optional)
- 2-3 Side Cutting Pliers (optional)
- 2-3 Wire Cutters (optional)
- Wire
- Paperclips
- Extension cord
- Rubber band

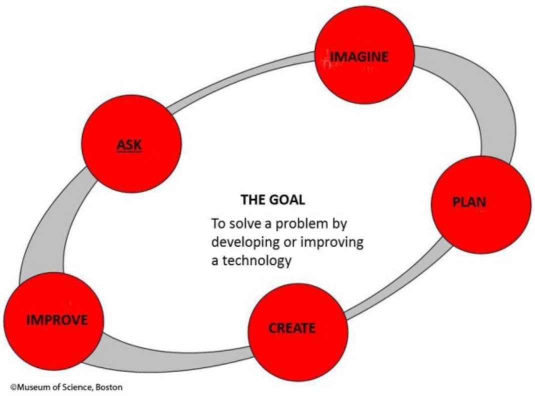
Preparation
- Prepare materials
- Check batteries
- Ask pupils to bring hairdryers

Working method
- Individually and in groups

Key ideas in this lesson
- Understand which parts are essential in a vacuum cleaner
- Understand why and how the parts can be connected

Context and background

The 'ask' element of the engineering process leads to an investigation of a hairdryer; pupils adapt what they to develop their design of a vacuum cleaner. They also discover how motors work with electricity, about current flow and how they can design a fan.



2.1 Introductory activity - a hairdryer- small groups - 20 minutes

Begin by explaining why they will be looking at a hairdryer when the design challenge is to build a vacuum cleaner. (It is more practical being on a smaller scale but shares some of the engineering design features of a vacuum cleaner) Provide a hairdryer for each group but also keep one in reserve to show pupils the important features. Let the pupils, in groups of 4 -5, look at the hairdryer (without taking it apart), investigate it and ask them questions like:

- What can they see?
- Which parts are needed for the hairdryer to work?

The teacher needs to point out the following parts, and ask questions such as what is it for? Where is it placed?.

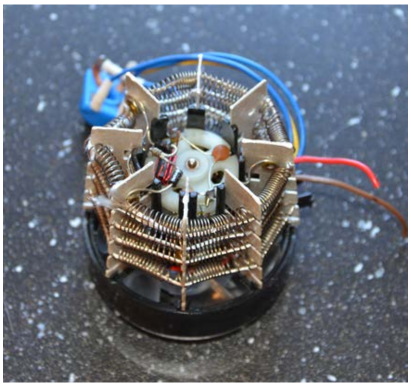
- Heating element - What is it for? *Heat is generated by the heating element and transferred to the air.*
- A fan - What is it for? *The fan is used to generate airflow in the hairdryer.*
- A motor - What is it for? Where is it placed? T*he small electric motor spins, which turns the fan.*
- Cables - What are these for? *Transferring the electrical current.*
- Switch - What is it for? *Basic models have two switches, one to turn them on and off, and one to control the rate of airflow. Some models have an extra switch that also lets you regulate the temperature of the airflow.*
- Electricity - What is it for? *Provide the current which makes the small electric motor spin, which then turns the fan.*
- Housing/case - What is it for? *All hair dryers have some type of heat sensor that trips the circuit and shuts off the motor when the temperature rises too much. But that can't be seen from the outside.*

The teacher writes all parts suggested by pupils on the white board.

Figure: hairdryer.

Figure: the back of a hairdryer.

Here are some pictures of a disassembled hairdryer and the parts - the motor and the fan that are attached to the motor.



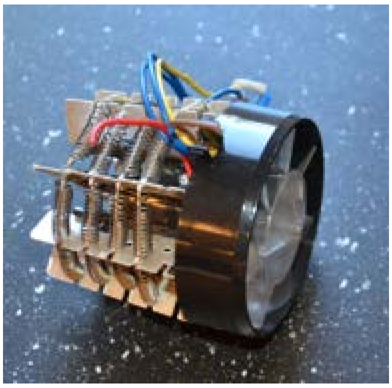


Figure: fan inside a hairdryer.

Figure: motor inside a hairdryer.

2.2 Get the motor to work - individually - 10 minutes

Important! Before starting

The teacher explains the difference between using voltage from the wall and from a battery and the important message is that: pupils can never experiment with the current from the wall. The batteries are only at 4,5 V and in the wall the voltage is 230V. So safety is of great importance while working with electricity. But when they work with batteries there is no danger.

Give a motor and a battery to all pupils. Ask them if they can get the motor to spin.
The battery terminals need to be connected to the motor's contact poles in order to get a complete electric circuit.

Figure: battery and motor in contact.

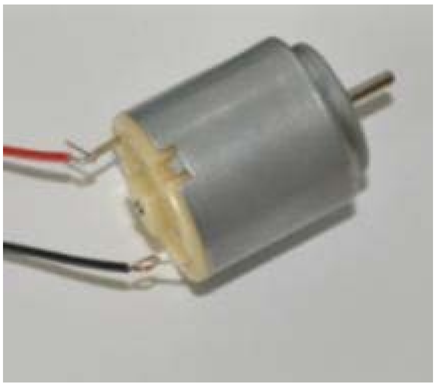


Figure: motor with wires on contact poles.

When the teacher sees that everyone has the motor spinning, they will know that the pupils have learned how to connect the batteries to the motor.
Ask the pupils why it starts working when it is connected to the battery.
Make clear to the pupils that:
The battery has two terminals, one negative and one positive.
When the motor and battery are correctly connected, the current can pass to the motor and it starts to work. They now have a complete circuit. A complete circuit is a closed path through which an electric current flows or may flow. If the circuit is broken, none of the components receives current. Historically, current flow has been defined from the positive

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to the negative terminal. (The movement of negatively charged electrons in an electric circuit is in the opposite direction). To simplify, it is said that the electricity goes from the positive to the negative terminal/pole.

2.3 Make a fan - individually - 20 minutes

Now the teacher gives all pupils half of an A4 sheet of paper. Ask the pupils to create a force by making a paper fan. (They can fold, or tear the paper and then attach it to the motor.) The design of the fan is not important as long as it blows air. . See the pictures below. Let the pupils look at the designs of other groups to get ideas about how the fan could look.

Figure: one type of fan.

Figure: the motor in contact with the battery.

If the paper fan blades keep falling off, take two small rubber bands, make a small hole with a needle in the first rubber band and attach it to the motor; to attach to the fan use another rubber band.

In this exercise, the students only use paper as material. The focus is on how differences in design change the effectiveness of the fan. In the design of the vacuum cleaner, the pupils are free to use other materials.

The motor can conduct electricity in both directions, but it spins in different directions when the poles are switched. Ask the pupils to see if they can get the fan to spin in the opposite direction. Give them a tip; switch poles so the current goes in the other direction.

2.4 Make a switch - small groups - 20 minutes (extension activity)

Resources (for 30 pupils)

- 6 -8 small motors 1,5-3V (one per group)
- 6- 8 Batteries 4,5V or 3x1,5 V
- Pieces of card board
- Wire
- Paperclips
- Paper fasteners
- 2-3 Side Cutting Pliers
- 2-3 Wire strippers

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The pupils now know how to make a circuit complete with a motor and battery. Let them first make a complete circuit with battery, wires and the motor. Then they can make a "switch" so they can turn the motor on and off.
Take pieces of cardboard. Make two holes in the cardboard so that paperclips and paper fasteners can be attached. Look at the picture. Attach the two loose ends of the wires, one to each paperclip. Move the paperclips so they can touch/not touch each other. In this way it is possible to turn the motor on and off..

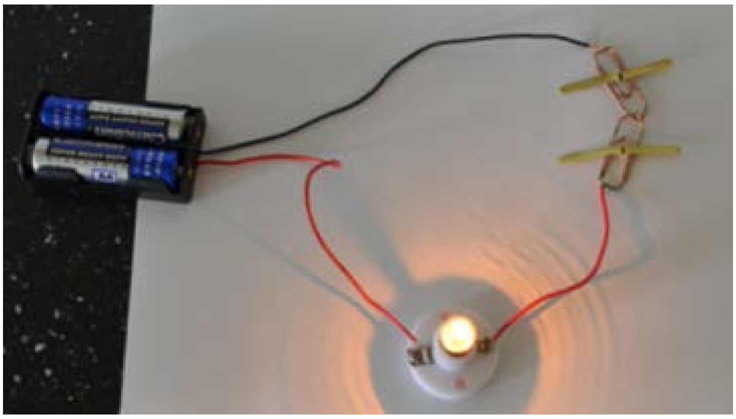
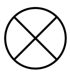
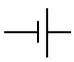
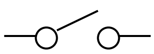


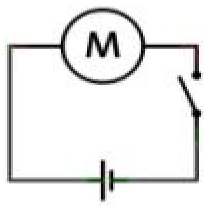
Figure: a switch in a complete circuit. In this picture we used a bulb instead of a motor.

2.5 Conclusion - plenary - 10 minutes

Summarise the learning objectives. Discuss with the pupils: Have they learned how to use batteries, small motors and fans? Can they identify and describe the different parts of a vacuum cleaner?
Summarise how to make a complete circuit and what direction the current goes in. The teacher can also demonstrate how we use symbols to describe circuits with different electrical components:
Here are some symbols:

	Motor
	Bulb
	Power source
	Switch

Here is the schema for motor, battery and switch:



Lesson 3 – Let's build!
Design and build your own vacuum cleaner.

Duration: 95 minutes (110 if optional activity included)

Objectives: in this lesson the pupils will learn

- how a motor with a fan can be used to move air through a tube;
- the importance of group work in arriving at creative solutions to a challenging problem;
- to use the EDP to successfully build a functioning vacuum cleaner.

Resources (for 30 pupils)

- 10 Motors (1,5V-3V)
- 10 Batteries (3*1,5V or 4,5V)
- Battery box (depending of witch batteries Worksheet 1. EDP plan.
- Worksheet 2
- Wire (Solid Core)
- 10 Plastic bottles
- Cardboard, with different thickness and looks
- Lollipop sticks
- Foam rubber
- Paperclips
- Rubber band (broad)
- Debris from the hole puncher
- 1 Saw
- 1 Gluepistol
- 1-2Wirestripper
- 1-2 Side Cutting Pliers
- Sticky tape
- 6 Scissors

Preparation

- Make copies of Worksheet 2
- Have construction materials ready

Working method

- In small groups of 2-3 pupils

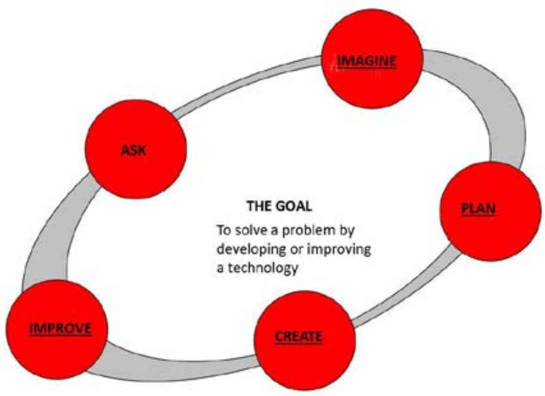
Key ideas in this lesson

- Using the Engineering design process to create a vacuum cleaner

Context and background

In groups, pupils work using a series of steps called the Engineering Design Process, to design a vacuum cleaner. The main focus for this lesson is for the pupils to create a product to solve the problem. Refer back to the story/cartoon in lesson 1.

In this lesson the pupils go through the steps 'image', 'plan', create' and 'improve'. They use the science they investigated in lesson 2 to meet the challenge.



3.1 Introductory activity - whole class - 5 minutes

Question the pupils: How can we now use what we know about electricity, batteries, motors and fans, and our own creativity to design and build our own vacuum cleaner?
The lesson is structured around the engineering design process so ensure the pupils have their EDP plan ready from the previous two lessons. Go back to the story and problem from Lesson 1. Tell the pupils that now is the time to undertake the design challenge. Then tell them about the design challenge. The activity is that the pupils **build and design a vacuum cleaner in groups**. Divide the class into groups, 4-5 pupils in each group trying to ensure a gender and attainment mix in each group. The task is completed when the vacuum cleaner sucks up any debris.
Tell the pupils about the design challenge and then start working from the steps in the engineering design process, the EDP plan. It is important that the pupils record their work in the EDP plan. They can also take pictures of their progress as they construct the vacuum cleaner.

3.2 Engineering design challenge - Ask, imaging and plan steps - small groups - 15 minutes

Ask - what do the pupils need to know? For example:

- What material can they use?
- What kind of dust will their vacuum cleaner be able to collect?

Criteria: The cleaner has to work with batteries and the motor but pupils can use other materials, like plastic bottles etc. The criteria for success is: If it can suck up any dust, or paper pieces from the hole puncher, then it is successful.

Imagine - ask pupils to imagine different solutions like the size of the vacuum cleaner, storage, placing the battery, etc. Give them a list of materials that they can use. The discussion stage is important.

Plan - let each team decide on one solution and start planning for its construction. Tell the pupils that they don't have to create filters or a dust bag; it is enough if they can get the dust into the cover.

Tip and warning! - The building stage can be quite challenging for the pupils. It is a good idea for the teacher to build a vacuum cleaner prior to the lesson and have it there so that pupils can see what the finished product might look like. However, emphasise that their way of doing things is important. There is more than one way to build a vacuum cleaner.
Before starting the activity the teacher should demonstrate how to fix materials together.
Our suggestion is that the teacher demonstrates how to fasten the motor. See examples below under point 4.Also the teacher should demonstrate how to use tools safely:
Demonstrate how the pupils can cut a plastic bottle. Be careful when using scissors and the saw. Both have sharp blades. Remind pupils how to use the side cutting pliers and the wire strippers.

3.3 Design and create - small groups - 60 minutes

Create - every group should design and make one vacuum cleaner. Remind the pupils that they can document their work/progress with photos.

The cover/ housing/case

The cover can be made from different kinds of bottles. Let the pupils decide the design of the cover. The easiest ones to cut with a scissor or a knife are soft plastic bottles, like used water/soda bottles. But you can use any round plastic bottles. To make a hole pupils can use scissors or a saw.

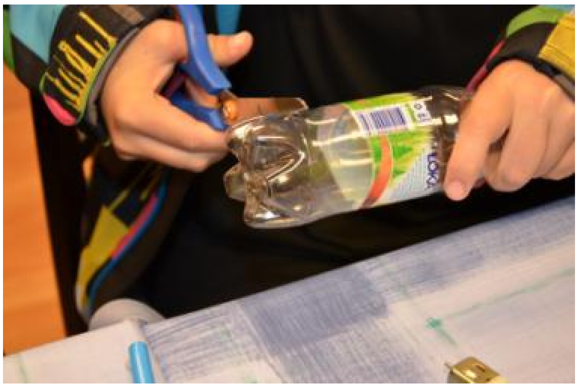


Figure: cutting the bottle.

– Design a fan and attach it to the motor

The fan can be made from many different materials. One material that is easy to work with and easy to adjust is cardboard. The cardboard can have different thickness and appearances: it can be from packaging such as cereals boxes, etc.

Let the pupils design the fan and then attach it to the motor. If the fan comes loose from the motor, use pieces of rubber band or sticky tape to attach it.

– Test the fan

Let the pupils try out the fan and motor before they start to fasten the motor to the cover. Here the pupils can use their previous knowledge to connect the motor to the batteries. If the fan fits into the cover and it starts sucking up dust or particles,, they can continue. If it is not sucking, but instead blows, try to switch poles in the connection with the battery. Then the motor will spin in the other direction and hopefully it will suck instead of blow. If the fan is too big, the pupils will need to adjust the fan before continuing. Holding a hand against the back of the cover and makes it possible to feel what is happening.

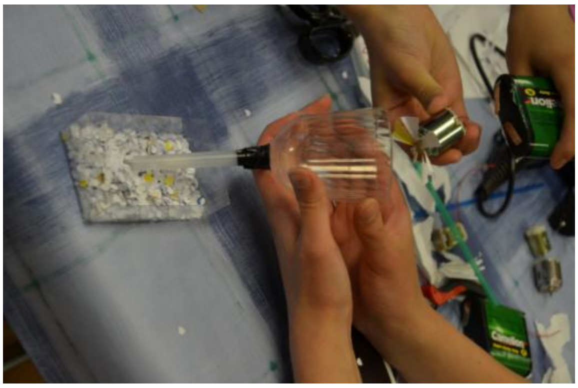


Figure: testing the vacuum cleaner.

– Fasten the motor

There are many ways to fasten the motor. The group can hold the motor with their fingers, or they can choose to fasten the motor to the cover. Here are some examples of how they can fasten it.

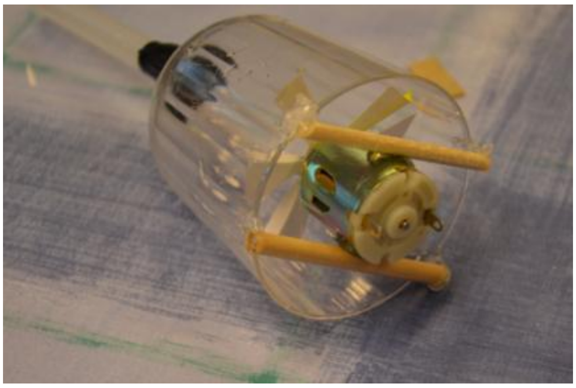


Figure: vacuum cleaner with lollipop sticks and glue.

Figure: vacuum cleaner with foam rubber.

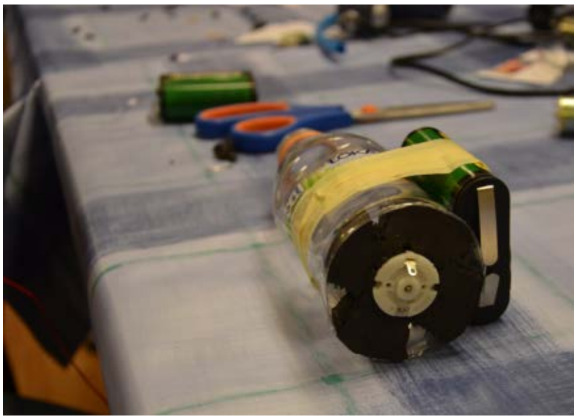


Figure: small holes so that the air can pass through.

Tip - Remember that air needs to be able to pass through the casing material: if necessary, make some small holes so that it can

– Fasten the battery/battery box

The battery/battery box can be fastened on to the outside of the bottle. The pupils can use their knowledge about how to strip wires and the connect the battery to the motor.

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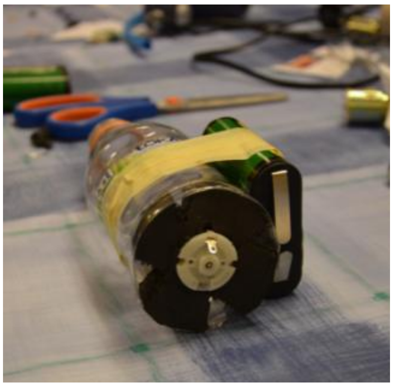

Figure: the battery could be fastened outside the bottle.

– Making a switch (optional additional 15 minutes)

The pupils can design a switch that can be used to turn the vacuum cleaner on or off. Here the pupils can use their previous knowledge about circuits (complete or incomplete) and materials which can /cannot conduct electricity).

Figure: vacuum cleaner with a switch.

Improve - ask groups to discuss how successful they have been and are there any obvious improvements they could make.

Remind the pupils to complete Worksheet1, and the EDP plan if they have any improvements or new ideas or questions.

3.4 Conclusion – plenary - 15 minutes

Summarise the learning objectives. Discuss with the pupils what they have learned about how a vacuum cleaner works, how a motor with a fan can be used to move air through a tube, and how to build and test different solutions for a vacuum cleaner.

When the pupils have finished their constructions, let them clean the classroom. Then tell them that in the next lesson they will show-case their designs to the rest of the class.

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Lesson 4 – How did we do?
Is the challenge met?

Duration: 75 minutes

Objectives, in this lesson the pupils will learn:
- that there are different ways to solve an engineering problem;
- that review and evaluation against criteria are important aspects of the EDP;
- that successful engineering depends on sound scientific knowledge.

Resources (for 30 pupils)
- their designed vacuum cleaners

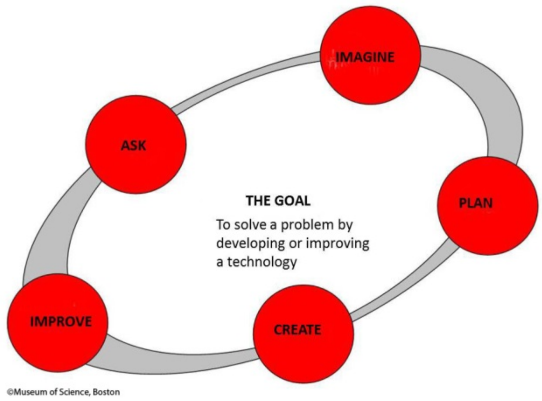
Preparation
- The pupils need to bring their designed vacuum cleaners from the previous lesson

Working method
- Working in groups and in the whole class

Key ideas in this lesson
- In this lesson the pupils reflect and analyse the EDP and their made artefacts against the agreed criteria. They also reflect on the science ideas that they have used.

Context and background

In this lesson the process and the product is evaluated. Is the challenge met? And how did the pupils apply the science they learned and how did they work with the design cycle. This is also the moment to present their solution to the problem and become proud of what they have learned and created.



4.1 Introductory activity - whole class - 5 minutes

Every group has one vacuum cleaner that they have designed and built. In this lesson, the class discuss their different solutions and evaluate the products. The teacher will need to tell the class how they should present to the class and how much time each group will have.

4.2 Presentation of the work - whole class - 60 minutes

Each group should tell the rest of the class about their vacuum cleaner. The teacher can promote discussion with the following questions:

- Is there anything you can still improve?
- Did anyone have a problem with not getting enough air into the cleaner? Where does the air come in and out? Does the air need to get out?
- Why does dust go into the cleaner?
- Did anyone have a problem with the direction of air flow? How did you solve it? What is the main difference between a hairdryer and a vacuum cleaner?
- How do you turn the vacuum cleaner on and off? Does everyone have the same solution or are there different solutions? Why does the cleaner start and stop?
- Why do most vacuum cleaners have a dust bag and filters?

Correct words and terms that the pupils should use:

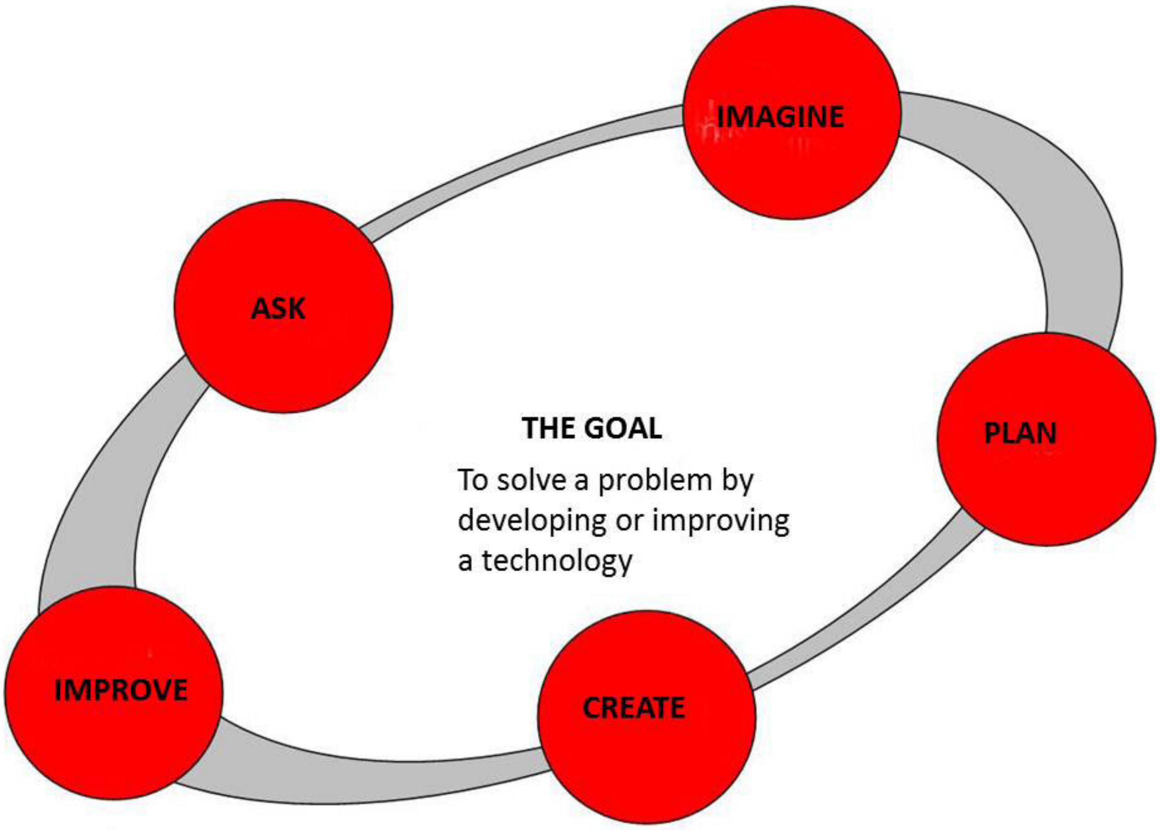
- Switch
- Motor
- Fan
- Electric cables
- Battery
- Circuit

4.3 Conclusion - plenary - 10 minutes

Summarise the learning objectives. Discuss with the pupils what they have learned about different ways of solving problems using the EDP. What have they learned by making their vacuum cleaner? Have they understood anything that they did not understand before? Discuss what science knowledge they have gained and applied during making their vacuum cleaner. Finally, has the unit inspired them to work as an electrical engineer?

Appendices

Engineering design cycle



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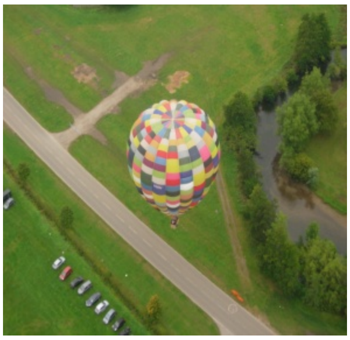
Story to set the context

You have just celebrated a fantastic end of school party in your classroom. Unfortunately, lots of confetti was used and the room is a mess. The cleaner is on holiday and has taken all the cleaning equipment. There is no dust pan and brush and cleaning up looks like it will take a long time. You have found some motors, electrical wires, batteries and paper in the science cupboard. You have also found lots of empty plastic drinks bottles from the party. One of the children suggested using a hairdryer to blow all the confetti away, however this would only result in more mess!

Can you become an electrical engineer to design, make and test a suitable cleaning device that will suck up all the mess and enable you to go home before it gets too late?

Worksheet 1 Lesson 0 – Engineering?











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Worksheet 1 Lesson 0 - Engineering? – Teacher notes

The pictures on the worksheet are intended to promote pupils' discussion about what engineering is, what engineers do and who could be involved in different types of engineering.

The pictures of the spider and snail present some interesting challenges. The pupils could for example, decide that the spider is 'engineering' a web and this could be related to other animal 'engineering' examples (such as a beaver building a dam). An interesting point to make is that it is more common to think of engineering in terms of the made world. We can however, learn from studying nature and the environment. For example, the material that spiders use for making a web has been copied to make a very strong material (Kevlar) that has many useful properties. Similarly, the snail has developed a useful strategy for travelling over rough surfaces to protect its soft body from being damaged. An interesting question is whether this would be useful to solve a problem in the human world (a good example is Velcro which was developed from the burrs of burdock plant).

The toys could be considered engineering since they demonstrate the application of cams but it is interesting to ask what materials they could be made from and who actually makes them. This is likely to lead to some gender issues (many of the class may think that toys are made for children by toy designers who are male).

A similar issue might arise when pupils discuss the knitted garment and the prepared meal - pupils may think that these are only made by women, and that they are not the product of engineering.

Some of the other pictures of sculptures and works of art might be perceived as not engineering and without any real practical purpose. This will raise a question about the links between engineering and art and whether or not a made object needs to have a practical purpose for it to count as being engineering.

The pictures are meant to stimulate engagement and dialogue about engineering. This could lead to a discussion about what is involved in engineering, in which you might choose to introduce the Engineering Design Cycle.

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Worksheet 1 Lesson 1-4- documentation of EDP process

Name:

Date:

Ask	What is the problem? What are the needs? What have others done?
Imagine	What are the constraints? What possible solutions might there be? Brainstorm ideas. Choose the best one.
Plan	Draw a diagram/image/sketch or write down your ideas. Make a list of materials you will need.
Create	Follow your plan and create it.
Improve	Test it out.

Ask

Write down all your questions and answers.

Imagine

Brainstorming. What solutions do you have? How will you design your vacuum cleaner? What parts will you need to use? How will you connect the pieces? Size? Practical solutions? etc. Write down/draw your ideas.

Plan

Draw a picture/sketch/diagram of your best idea in the Imagine step. Explain the details and write a list of materials you will need to construct it.

Create

Tip! Take pictures during your constructing.
Test!
What happened when you tested your design?
What parts worked well? How do you know?
What parts did not work? Why?
How could you improve your design?

Improve

What parts of your design needed to be improved? How do you know?
Draw/write down or take a picture of your improved design. Describe the improvements

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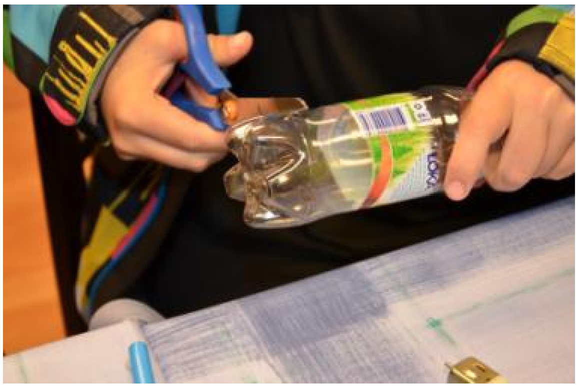
Worksheet 2 Lesson 3- design and build your own vacuum cleaner

Name:
Date:

a. Have your EDP plan ready with the ask step, imagine step and plan step.
b. Now it is time to **create**, to build your own vacuum cleaner. Below, is a description that you can follow. But feel free to make your own design.
c. Remember to document every step you take while constructing, either write it down or take a photo.
d. If you need to make changes, have new ideas about the design, or you have more questions that have to be answered before you can continue constructing or during your constructing, look into the EDP plan and go back to that step and write it down (document).
e. The task is completed when the vacuum cleaner sucks up any debris.

1. The cover/ housing/ case

The cover can be made from different kinds of bottles. Choose one bottle that your group agreed on in the planning and start designing. To get the first hole you could also use a saw and then scissors. Be careful! Scissors and saws have sharp blades.



2. **Design a fan and attach it to the motor**
   Design a fan and then attach it to the motor. If the fan comes loose from the motor, use pieces of rubber band on both sides of the fan.

3. **Test the fan**
   Try out the fan and motor before you start to fasten the motor to the cover. Connect the batteries to the motor. If the fan fits into the cover and it starts sucking the "small paper pieces," you can continue to the next point, 4.
   If it is not sucking, but instead it blows, try to switch poles with the connection to the battery. If the fan is too big, you need to adjust the fan before continuing.

4. **Fasten the motor**
   There are many ways to fasten the motor. You and your group can choose to hold the motor with your fingers, or you can choose to fasten the motor to the cover. Remember that air has to be able to pass through the material, and you may need to make some small holes. Try holding your hand at the back of the cover and see what happens.

5. **Fasten the battery/battery box**
   The battery/battery box can be fastened on the outside of the bottle. Use your knowledge to work out how to connect the wires.
   Remember to document your work and fill in worksheet 1, and the EDP every time you have a new idea, another solution and/or improvement.
   When you are satisfied with your work you can develop/make a switch for your vacuum cleaner.

6. **Making a switch (optional)**
   Use your knowledge about switches and make one for your own vacuum cleaner.

Science notes for teachers about electricity and vacuum cleaners

Some key science concepts, knowledge and skills involved in Lesson 2

- constructing a simple electrical circuit containing battery, wires, a motor (and fan) and a switch
- a complete circuit is needed for an electrical current to flow
- the battery terminals need to be connected to the motor's contact poles in order to make a complete electric circuit
- the battery has two terminals: one negative and one positive
- using a simple electrical circuit with a motor to make a paper fan rotate
- the design of the fan can change its effectiveness
- the motor can conduct electricity in both directions and spins in different directions when the poles are reversed
- if the circuit is broken, none of the components receives current and they will not work
- there is a difference between mains voltage (230V) and battery voltage (4.5V)
- symbols and diagrams are used to describe simple electrical circuits

What is electricity and which material conducts electricity?

The Greek word for amber is 'elektron', from which the word electricity is derived. The Greeks amused themselves by rubbing a rod of amber with a cloth and then picking up feathers, leaves, etc.; they knew nothing about why this happened.

Electricity is a form of energy. It is the flow of negative charge caused by the movement of electrons. All material is made of atoms. An atom if comprised of a core (nucleus) and shells. The nucleus consists of positively charged protons and neutral neutrons Surrounding this are 'shells' of moving electrons that are negatively charged. If you want to understand this further, look at the website below:
http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/atomic/atomstrucrev1.shtml

In an atom there are as many protons as electrons, which means that it is neutral. When the balancing force between protons and electrons is upset by an outside force, an atom may gain or lose an electron. When electrons are "lost" from an atom, the free movement of these electrons constitutes an electric current.

In some materials, such as water and metals, the electrons move easily through the material. These are good ***conductors*** of electricity. In copper wire, for instance, some electrons are not tied to specific atoms and can move freely within a sea of electrons. This is why copper wire is good for circuit building. In other materials, such as plastics and amber, electrons do not move so easily, and consequently they do not allow an electrical current to flow.

Electricity can be converted to heat, light and movement. Electricity can be used to control technology. It can be turned off and on using switches and it may also transfer energy over long distances. However, in principle, we cannot store electricity.

About simple electrical circuits

A simple electrical circuit is a closed path within which electrons move. Imagine a simple circuit made of a battery, a device or component (such as a motor or a bulb) connected by wires. What causes electrons to move?

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Within a ***battery*** there is a chemical reaction that creates a buildup of electrons at one terminal (the ***anode***) and a relative deficit of electrons at the other terminal (***cathode***). This results in an electrical difference between the two terminals (potential difference). When the battery is connected, this difference causes a flow of negative charge from one terminal to the other (anode to cathode). This flow of electric current is a consequence of the fact that electrons are negatively charged and will therefore repel each other, such that they move towards a place where there is less negative charge (ultimately the cathode which is positively charged). Any component or device within a circuit will create a ***resistance*** to the flow of negative charge. The movement of negative charge through the component will cause energy transfer to occur (a bulb will light up, a motor will turn and both will become warm). The battery is the *driving force* of the circuit and eventually, the chemicals that create the separation of charge within the battery are exhausted and the battery 'runs out'.

Current, Voltage, Resistance and Power

Current is the flow of electrons and, consequently, the flow of negative charge within a circuit; the more electron movement, the greater the current. Current is measured in ***amperes*** (A) and is defined as the rate of flow of charge. It is a measure of the amount of electric charge passing a point in an electric circuit per unit time. Historically, current flow was represented as moving from the positive terminal of a circuit to the negative terminal. The movement of negatively charged electrons in an electric circuit is actually in the opposite direction (from negative to positive). The current starts to flow the instant the battery is connected and the switch is closed. If you measure the current at any point in the circuit it will be the same.

Voltage is the difference between charges. Voltage is measured in volts (V). Every battery carries a voltage rating (in Lesson 2 we use 1.5v and 4.5v batteries). The voltage rating indicates the difference in charge between the battery's terminals. The bigger the difference, the greater the 'push' the battery can exert (a 4.5v battery delivers 3 times as much 'push' as a 1.5v battery). This difference (or 'push') enables the electrons to move so as to try to compensate for these differences. A more appropriate name for voltage is ***potential difference***.

Resistance within a circuit inhibits the current flow and causes the electrons to move more slowly. Any devices or components (such as a bulb or motor) create resistance to the flow of current. If a device is to work, the 'push' from the battery must be strong enough to overcome the resistance the device creates. This means that devices usually carry a voltage rating that needs to be matched to a battery of appropriate voltage rating. Resistance is measured in ohms (Ω).

Power refers to the rate of energy transfer. Light bulbs that we use in our homes have a power rating measured in watts (W). A ***watt*** is equivalent to one joule of energy per second.

About vacuum cleaners

The name "vacuum cleaner" is a bit of a giveaway when it comes to understanding how your machine works: vacuum cleaners work by suction. Indeed, "Suction cleaner" would be a better name than vacuum cleaner, because there's no actual vacuum involved. The mechanical / electrical part is really a strong motor that blows air, usually out of the top or back of the cleaner. This creates a suction force at the bottom (where the dust gets pulled inside). Vacuum cleaners all work on the same principle....if you attach a motor that blows air (say a fan) to one end of an object that has an opening at the other side, it can work in the same way. It causes air to flow first inside the object using a fan, and then out through the back/top of the object.

If you want to know more about how vacuum cleaners work you can look at these websites:
http://home.howstuffworks.com/vacuum-cleaner.htm
http://www.explainthatstuff.com/vacuumcleaner.html

A problem with the suction design is that filters always become blocked. Modern vacuum cleaners overcome this by a design based on a vortex principle. Find out more about this at:
http://home.howstuffworks.com/vacuum-cleaner4.htm

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Some pupils' ideas about electricity and simple electric circuits

Children's thinking about the natural world comes from their everyday experiences. They may not represent the established current scientific view but they usually contain sensible reasoning based on observation and interaction. Offering opportunities for children to challenge their thinking through activity is more likely to shift their perceptions than telling them facts. However, this presents a significant pedagogical task. It is extremely demanding for learners at all levels and ages to accommodate new ideas about a particular phenomenon, especially when these seem to contradict common sense reasoning. Although through research we have some insight into the ideas pupils are likely to have in particular conceptual domains in science, often, pupils have difficulty in articulating their thinking so there is a need to exercise some caution in making assumptions about their reasoning. This highlights the importance of providing opportunity for children to discuss their thinking.

Ideas about electricity

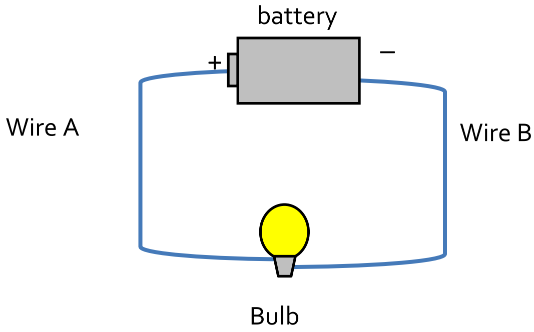
Generally, children are well aware of the many uses of mains electricity in everyday life, particularly in terms of generating heat, light and movement (1). They are likely to have some knowledge of the dangers of mains electricity but it is important to develop this through Lesson 2. Some may associate electricity with the mains supply rather than batteries, but most know that batteries are important in making devices (such as toys) work. Allen (2) suggests that pupils construct ideas similar to the adult notion of energy. The battery gives some of its 'stuff' (called various names by pupils such as: *electricity*, *energy*, *power*, *juice*) to the device to make it work. The 'stuff' get used up by the device and when the battery runs out of 'stuff', it no longer works and is dead. The Nuffield Primary Science Teachers' Guide (1) demonstrates a range of primary pupils' ideas about what electricity is like. These include notions of it being invisible, travelling very fast and flowing. One child comments: 'Electricity is like magic'. As the concept of electrons and negative charge is likely to be too challenging for pupils of this age, the teacher may wish to tolerate the range of ideas on what electricity *is*, while emphasising the notions of current flow within the circuit.

Ideas about a simple circuit

This challenge requires that pupils know that a complete circuit is needed in order to make a device (the motor) work. This entails practical experience of circuit building, ensuring connections are made carefully and outcomes observed. While some pupils know that a battery has two connections, others may not be aware that components such as a motor also have two connections, or that reversing the connections of the motor to the battery makes the motor turn in the opposite direction. They also need to recognise and explore the making of breaks in the circuit. Lesson 2 provides opportunity for the development of technical skills of simple circuit building.

There is a difference between *knowing how* to connect components to make a complete circuit and *understanding why* this happens. Understanding why is much more challenging. Research shows that pupils possess a range of explanations for the behaviour of simple circuits (3). Figure 1 shows the connections needed to make a complete circuit to light a bulb.

Figure 1. A complete circuit to light a bulb



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Sometimes children possess a 'unipolar model' in which they think that only one wire is active. Indeed mains electricity *seems* only to have one wire, so this is understandable. In this view, wire A (in Figure 1) is often seen as the active wire as pupils reason that 'electricity' comes from the +ve terminal of the battery. While they may come to know that the second wire is needed for a complete circuit, they may still think that it doesn't play an active part in making the bulb light.

Some pupils regard 'electricity' as flowing from both terminals of the battery. They may think these are two different types of 'electricity' that meet at the bulb and cause it to light (*'a clashing currents'* model). Others may hold a *'current consumed'* model where they think that the returning wire carries less 'electricity' as some has been used up at the bulb (wire B contains less 'electricity' than wire A). In the *scientific model* current is *conserved* within the circuit and both wires contain the same current flow (wire A = wire B). For many learners, this fails to make sense as they reason that something *must* get used up at the bulb.

In order to understand why current is conserved, the learner must understand that *energy is transferred* at the device (bulb, motor etc.). The energy of the movement of negative charge is transferred as movement, light and heat as the device works. The bulb lights or the motor turns and they both get warm. This is a counterintuitive and abstract idea that is very challenging. Science teachers often employ analogies to help pupils in explaining their observations. Asoko and de Bóo (4) suggest a range of analogies such as the example of a bicycle chain in which the battery is represented by the person pedalling the bicycle and the bulb (or motor) is represented by the bicycle wheel. The wheel turns and the bulb 'lights'. Current conservation is illustrated by the moving chain that does not get 'used up'. All analogies, however, have limitations that teachers must be aware of. In the bicycle analogy, neither the wires nor energy have physical representation. The teacher will need to use their professional judgment in deciding what is appropriate for their pupils.

For the purposes of this challenge, the teacher may focus on the technical enterprise of building circuits. Some pupils will need a lot of circuit building experience using different components before they are able to generalize the idea of a complete circuit. Lesson 2 allows for the development of concepts of flow within the circuit and energy transfer in the form of movement and heat at the motor. Furthermore, the opportunity to build and incorporate switches contributes towards knowledge of a complete circuit.

References

(1) Nuffield Primary Science: Teachers' Guides (Ages 7-12): Electricity and Magnetism (1995) HarperCollins Publishers: London

(2) Allen, M. (2010) *Misconceptions in Primary Science*. Open Univesrity Press: Berkshire, England

(3) Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V.(1994) *Making Sense of Secondary Science.* Routledge : London.

(4) Asoko, H. & de Bóo, M. (2001) *Analogies & Illustrations: representing ideas in primary science*. Association for Science Education: Hertfordshire.

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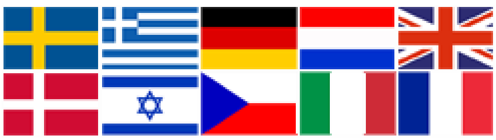

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