TESSA

Teacher Education in Sub-Saharan Africa

The Open University

Secondary Subject Resources

Science

Biology
Chemistry
Physics

Secondary Subject Resources

Science

TESSA (Teacher Education in Sub-Saharan Africa) aims to improve the classroom practices of primary teachers and secondary science teachers in Africa through the provision of Open Educational Resources (OERs) to support teachers in developing student-centred, participatory approaches. The TESSA OERs offer activities for teachers to try out in their classrooms with their students, together with case studies showing how other teachers have taught the topic, and linked resources to support teachers in developing their lesson plans and subject knowledge. TESSA OERs have been collaboratively written by African and international authors to address the curriculum and contexts. They are available for online and print use (http://www.tessafrica.net). Secondary Science OER are available in English and have been versioned for Zambia, Kenya, Uganda and Tanzania. There are 15 units. Science teacher educators from Africa and the UK, identified five key pedagogical themes in science learning: probing children's understanding, making science practical, making science relevant and real, creativity and problem solving, and teaching challenging ideas. Each theme is exemplified in one topic in each of Biology, Chemistry and Physics. Teachers and teacher educators are encouraged to adapt the activities for other topics within each subject area. We welcome feedback from those who read and make use of these resources. The Creative Commons License enables users to adapt and localise the OERs further to meet local needs and contexts.

Contents

Secondary Subject Resources

Science

Module 1 Biology

ENGLISH

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Contents

Section 1: Classification and adaptation

Theme: Probing students' understanding

Learning outcomes

By the end of this section, you will have:

- used brainstorming to probe students' understanding of adaptations to different habitats;
- planned questions at different ability levels to help students classify organisms they have found;
- given students the opportunity to devise a key to demonstrate their understanding of the principles of classification.

Introduction

At the end of teaching a topic, teachers usually set a test or exam to find out what the students have learned. They are often dismayed to find that it is not as much as they expected but by this time it is too late to help students. A good teacher will find out what students understand as they go along and what the students are finding difficult, and help them to make progress.

This unit has three short activities that will fit into your normal teaching about **classification and adaptation** and will show you how to find out what your students understand. The activities will encourage you to bring living organisms into your classroom and will help to develop your students' understanding. Don't worry – the activities won't prevent you from finishing the syllabus; they are quite short and will help your students to learn. Once you have tried these activities, you will be able to adapt them when you teach other topics.

1. Creating a learning environment

Students have their own ideas about a topic and an effective teacher takes account of these ideas when teaching. So a good way to start teaching any topic is to find out what your students already know about it. You may be surprised about what they have learnt from newspapers, peers, adults, older brothers and sisters, and observations. Often their ideas are not the same as the scientific ideas we want them to understand. Sometimes they only begin to realise how much they already know when you give them the chance to think out-loud with each other, in a brainstorming activity. By asking simple, open-ended questions you can make sure that as many students as possible take part in the discussion and you will have a better understanding of what they know.

As a biology teacher, if you are lucky enough to have your own classroom, you should bring in examples of living creatures to keep in the classroom. Pot plants, small insects that the students take it in turns to feed and seeds to plant will all be resources you can draw on in your lessons. Many students may already know a lot about animals and plants. You need to give them the chance to demonstrate their knowledge and interest, but you also need to challenge them to think about why certain living things have certain characteristics. While your syllabus may specify particular organisms that the students should know about, both adaptation and classification are topics based on one or two key ideas that can be applied to the many varied organisms that are found on Earth.

Case study 1 shows how a teacher organised her classroom to inspire and motivate her students and **Activity 1** describes a brainstorming session that will provide material you can use as examples throughout the topic.

Case study 1- Creating a stimulating learning environment

Mrs Yara had been teaching biology in MoshiJunior High School for two weeks. She was lucky enough to have her own classroom. Before she started teaching she spent the last week of the holiday preparing her room. She collected pictures of animals from magazines and tourist brochures, making sure she had one from each of the main vertebrate groups and some invertebrates. She brought in a pot plant from home and took some cuttings; a friend gave her a cactus and she bought an old glass tank from a market stall. She collected some insects and filled the tank with twigs, leaves and created a living space for the insects. To do this she used the guidance in **Resource 5** . Finally she planted some seeds that were beginning to sprout.

When she started to teach classification, she divided the class into groups of four and gave them 10 minutes to go round the room and look at all the pictures, the plants and the insects. For each one they had to try and identify it and say where it would normally live.

She then gathered them round the front and asked questions about what they had seen. She started off with simple, closed questions such as the name of the organism and where it lived, and moved on to harder questions that challenged them to think about the different adaptations. On the board, she wrote the names of the plants and animals and asked them how the animals could be divided into groups. Finally she asked them about other plants or animals that they knew about and was delighted when Joshua told the class about a carnivorous plant that he had seen.

Mrs Yara was very impressed by how observant they had been and realised that they knew and understood quite a lot about how animals were adapted to their habitats. Finally she asked for volunteers to take responsibility for the plants and insects in the classroom, and was very pleased with the responses.

Activity 1: Conducting a brainstorm

Choose a habitat like the sea, grasslands or a rain forest.

Gather your students round the front desk and ask for some examples of animals that might live in the chosen habitat. You are going to use brainstorming (see **Resource 1**) to build up a picture of how much your students already know about animals, how they are adapted and how they can be classified.

Once you have gathered some names, you could ask them about how they are adapted for that environment, which ones are vertebrates, which ones are mammals, etc. This is the sort of topic about which students will probably have quite a lot of general knowledge, but have perhaps not thought about it in a scientific sense.

Build a spider diagram on the board using their ideas. You could link specific adaptations to both habitat and mode of life. Encourage them to suggest both structural and behavioural adaptations. You could use coloured chalk to distinguish these. **Resource 2** shows an example of a diagram that another class produced. It is important that the one you produce is based on what your students suggest.

2. Peer assessment and using keys

In **Activity 1** you have gained some understanding of the breadth of knowledge in the class and have consolidated their understanding of how an organism's characteristics adapt them for a particular habitat or way of life. Like Mrs Yara you might have realised that as a class, your students already seem to know quite a lot. You will need to start to find out more about your students' individual understanding. Teachers often do this by setting questions, or by asking them to write about an experiment or activity they have done. Sometimes, however, it is helpful to let them explain their ideas using a drawing or a model and to offer them a choice about what they do. This gives the students who are not so good at writing the chance to demonstrate what they can do and helps them to feel more confident. Confident students learn better and often try harder.

In **Case study 2** the teacher uses this technique and gets his students to mark each other's work. He does this so that they have the opportunity to learn from each other, as well as from him. **Activity 2** involves getting your students to construct a classification key. This will tell you whether or not they understand the principles of classification, and doing the activity will help their understanding.

Case study 2: Organising peer assessment

For homework, Mr Uno asks his class to draw a picture of an animal of their choice. He asks them to choose a vertebrate that lives in their country. If they prefer, they can find a picture in a magazine, cut it out and stick it onto a page, so that they can write around it. In class, he asks them to annotate their picture to explain which classification the animal belongs to and how it is adapted to where it lives and its way of life. Before they start he gathers the students round the front and asks them to think about what they would need to do to get a high mark for this activity. He writes their ideas on the board and explains that they are going to use these statements to mark each other's work. **Resource 3** has some ideas about how to help students mark each other's work.

While the students are working, he goes round and looks at what they are doing. He asks questions to guide them and makes sure that they explain things as fully as they can. After 20 minutes, they swap work with someone who has chosen a different animal. They use the statements on the board to help them make some comments on the work. Finally, the students have 5 minutes to finish off their poster, taking into account the comments from their friends.

Mr Uno collects the posters. He is very impressed by the quality of the work and pleased with the comments they made. Some students have clearly acted on the advice from their friends and improved their work.

Activity 2: Using keys to promote thinking

Your students will need to know some of the main classes of animals. It is easy to test whether they know the names of the groups, but less easy to establish whether they understand the principles of classification. This activity will help with understanding the idea of a hierarchy.

To help them understand the principles we use to put living organisms into groups, you can use an identification key. First you will need to show them a key and let them practice using it (**Resource 6**). Then, give them (or let them devise) a list of animals that are common to your local area and ask them to work in groups to construct a key that would enable a friend to identify the animals they have chosen. Alternatively you can use the made up animals given on the resource sheet and ask them to construct a key.

Ask them how they decided on the key questions. Let them try out other people's keys.

3. Encouraging students to ask questions

There is no better way of motivating and engaging students with this topic than using living creatures. In the final activity you are going to collect some insects from the school grounds, or visit a local wildlife park or farm, and think about how you can use questioning to really find out what your students are thinking. It is important to make sure that your questions challenge them. **Resource 4** reminds you about the different types of questions that you should be asking. It is a good idea to plan the questions that you could ask before the lesson. You can ask questions of individuals while they are working and then finish off the activity with questions to the whole class. Think about how you will respond to their answers. You could ask several people the same question then ask the students to select the best one. You could also ask a follow up question: 'Why do you think that?'

Getting your students to ask the questions is a very good way to find out what they are thinking, as the teacher in **Case study 3** found when he invited a wildlife ranger into the classroom.

Case study 3: Welcoming visitor into the classroom

Mrs Essuman's brother, Joseph works for the local wildlife park as a ranger. It is his job to go round the exhibits with the visitors and tell them all about the animals on display. She invited him to come to school to talk to the class.

Joseph started by telling the students about his job and what he does every day. He told them about the qualifications he has and what he needed to do to get a job in a wildlife park. Finally, he told them some stories about some of the animals that he looks after. The students were very interested. Joseph talked about the animals' behaviour and the sorts of things they liked to eat. Mrs Essuman was pleased and surprised at how many questions her students wanted to ask him about the wildlife park. They were particularly fascinated by the skulls and teeth that he brought to show them. He played a game with the students in which they had to ask questions to try and work out which kind of animal the teeth came from. He could only answer yes or no, so the questions had to be phrased very carefully.

After the visit, some of the students asked Mrs Essuman how they could become a wildlife ranger.

Activity 3: Identifying living creatures

For this activity you should help your students to collect small animals in the school grounds. **Resource 5** will give you some information about organising the activity..

Use **Resource 4** to help you plan some questions to ask to check your students' understanding of classification and using a key. The students should work in groups and you should go round asking each group questions. Encourage them to ask each other as well. You could start with simple, closed questions designed to make them observe carefully. How many legs has it got? Does it have antennae? Once they think they know what it is, ask them to classify the animal. Get them to explain why they have chosen a particular group. Are you sure it is in that group? How do you know is it not an *X*?

They should try to classify the animals they have found using a suitable guidebook or biology textbook for your country. For each one they should be able to classify it at more than one level and should be able to give reasons for their choice. The majority of animals are likely to be arthropods, which should be classified to at least class level.

If you have a local wildlife park then a visit there would be a good alternative to this activity. You will need to go beforehand and devise activities that your students could do.

Resource 1: Brainstorming

Teacher resource to support teaching approaches

What is brainstorming?

Brainstorming is a group activity that generates as many ideas as possible on a specific issue or problem for the group to then decide which ideas offer the best solution. It involves creative thinking by the group to think of new ideas to address the issue or problem they are faced with. Brainstorming helps students to:

- understand a new topic
- generate different ways to solve a problem
- be excited by a new concept or idea
- feel involved in a group activity that reaches agreement.

Brainstorming is particularly useful for helping students to make connections between ideas. In science, for example, it can help them to appreciate the links between the ideas they are learning in class, scientific theories and their everyday lives.

A brainstorm at the start of a topic will give you as a teacher a good idea about the extent and depth of knowledge already held by the class. It will not tell you about individuals' understanding, but it will provide a wealth of collective ideas that you can refer back to as the topic progresses.

How to set up a brainstorming session

Before starting a session, you need to identify a clear issue or problem. This can range from a simple word like 'energy' and what it means to the group, or something like 'How can we develop our school environment?' To set up a good brainstorm, it is essential to have a word, question or problem that the group is likely to respond to. The teacher can gather the class round the board and run the session, or, in very large classes, divide the class into groups. The questions can be different for different groups. Groups themselves should be as varied as possible in terms of gender and ability.

There needs to be a large sheet of paper that all can see in a group of between six and eight pupils. The ideas of the group need to be recorded as the session progresses so that everyone knows what has been said and can build on or add to earlier ideas. Every idea must be written down, however unusual.

Before the session begins, the following rules are made clear:

1. Everyone in the group must be involved.
2. No one criticises anyone else's ideas or suggestions.
3. Unusual and innovative ideas are welcomed.
4. Lots of different ideas are needed.
5. Everyone needs to work quickly. Brainstorming is a fast and furious activity.

Running the session

The teacher’s role initially is to encourage discussion, involvement and the recording of ideas. When pupils begin to struggle for ideas, or time is up, get the group (or groups) to select their best three ideas and say why they have chosen these.

- summarise for the class what they have done well
- ask them what they found useful about their activity: what did they discover in the brainstorming that they didn’t realise before?

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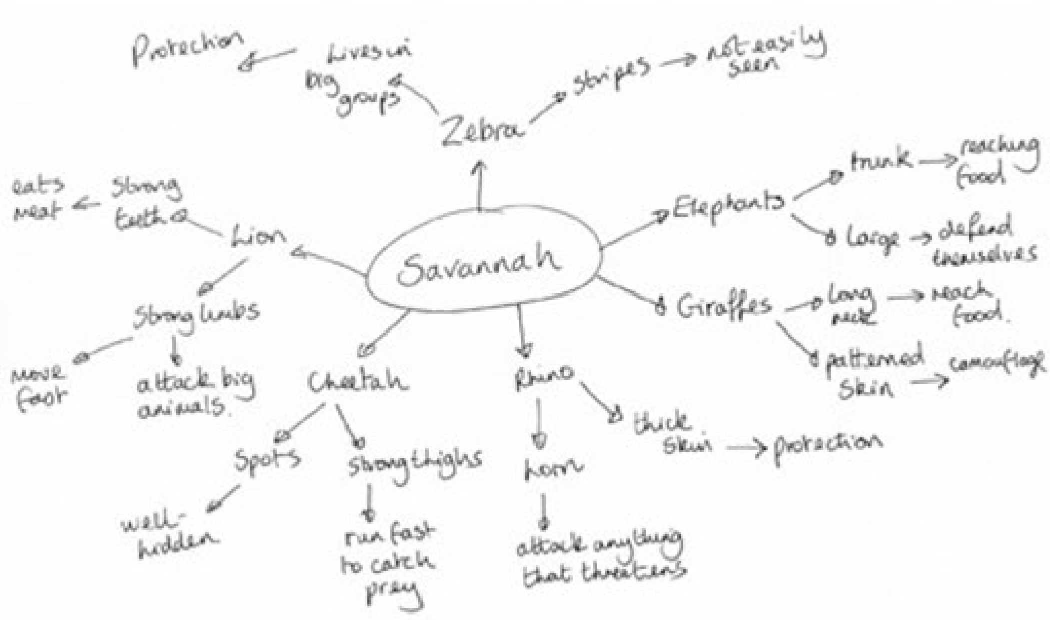
Resource 2: Example of a mind map

Background information / subject knowledge for teacher



Resource 3: Peer assessment

Teacher resource to support teaching approaches

Peer assessment

Students can learn a great deal by looking at and assessing each other's work. It can help them to evaluate their own work more objectively and it can help them to understand the assessment criteria. Taking part in peer assessment can also help students to be more involved in the assessment process and take more responsibility for their own learning.

It is important that students understand how to evaluate and they need to take it seriously.

In order to get some of the benefits of peer assessment, you need to teach your students how to do it:

- They need some basic ground rules.
- They need very clear criteria against which to make the assessments.

Ground rules

When commenting on other people's work they should start with at least two positive comments:

'I like the way you did…'

'That is a really good idea…'

'You have made it very clear…'

The first few times you try this with a class, it is best to limit them to making positive comments or suggestions ('it would be really good if you had coloured in that part as well…')

Any criticisms should be worded in terms of things that could be improved or developed, rather than a negative point.

'I liked the way you …, it would be even better if…'

'That was a good decision, but perhaps you could have done … as well'

Clear criteria

Your students will need very clear guidelines about what they are looking for. These can be in the form of questions. For the poster in **Case study 2** a set of suitable questions would be:

- Does the drawing/picture make it clear what type of animal it is?
- How many adaptations have been identified?
- Are the reasons for the adaptations clearly explained?
- Did you learn something from this poster?
- Is the work clear and well-presented?

When your students have had the chance to look at other students' work, they should have the opportunity to look at their own again and make some changes if they wish. This process will make them more aware of the assessment process and more critical of their own work.

Resource 4: Questioning

Teacher resource to support teaching approaches

Questioning

Good questioning is really important and is not as simple as it first may seem. It can help you develop good relationships with your students, it can help your students to organise their thoughts and therefore help them to learn, and it can provide you with valuable insights into their thinking. Good questions can promote thought, encourage enquiry and help with assessment.

By thinking carefully about the sorts of questions that you can ask, you will improve your teaching.

It is helpful to think of questions as being ‘open’ or ‘closed’ and ‘person’ or ‘subject-centred’.

Closed questions have a single correct answer. They can reassure students and help you to find out what they remember. But too many closed questions can limit the opportunities to explore thinking and develop understanding. They are often undemanding and can be quite threatening if the student lacks confidence.

Open questions have no right answer, or several right answers. They give you opportunity to find out what your students are thinking, and can be less threatening for some students.

Subject-centred questions ask things like ‘what goes into a plant?’ and ‘what sort of rock is this?’

Person-centred questions focus on the student and are less threatening and more learner-friendly: ‘What do you think goes into the plant?’ ‘What do you notice about the rock?’

A committee of educators chaired by Benjamin Bloom devised a taxonomy of types of questions in which they identified ‘**lower order questions’** and ‘**higher order questions’**. Research shows that lower order, recall-type questions tend to dominate classrooms. This leads to an emphasis on remembering facts and reduces the opportunities for creativity, thinking and developing understanding (see table).

It is important that you **plan** your questions appropriately. When you are doing a practical demonstration, for example, or introducing a new topic, write out a list that includes some lower order and some higher order questions. This way, you will be using questions to help your students to learn. Just like every aspect of teaching, you need to practise! You also need to think about how you respond to your students’ answers. Try and give them time to think, ask several students the same question or let them discuss the answer before they respond.

Conventionally, students are asked to put their hands up when they answer a question. You probably find that the same students frequently put their hands up and some do so very rarely. It can be very effective to ask specific students to answer your questions and **not** to ask them to put their hands up. Everyone will have to listen as they know that they might get asked. When you first start doing this, make sure that you direct easy questions at students who you know will find the work difficult. If they can successfully answer some of your questions, they will become more confident.

Bloom's taxonomy of questions

Type of questions	Purpose	Examples
Lower order questions		
Recall	To see what your students remember	Who is? What are? Where are? When did?
Comprehension	To see if your students understand what they can remember	Explain why? What are the differences between? What is meant by?
Application	To see if your students can use their knowledge	How would you classify these invertebrates? What is the evidence that this is a metal?
Higher order questions		
Analysis	To help your students think critically To see if they can make deductions and draw conclusions	Why? What do you think will happen if? What do your results show? What would be the effect on?
Synthesis	To help your students create new ideas from existing information	What would happen if there was no friction? Suppose the Earth rotated at half the speed?
Evaluation	To encourage your students to form opinions and make judgments	How effective is? Which is best and why? What do you think?

Adapted from Amos, S. (2002) 'Teachers' questions in the classroom' in Amos, S., Boohan, R. (eds) Aspects of Teaching Secondary Science, *London, RoutledgeFalmer.*

Resource 5: Working with insects

Background information / subject knowledge for teacher

Collecting small animals

Caution: You will need to research the 'bugs' in your local area and be aware of any that are poisonous or dangerous.

You will also need a reference book that describes the insects that might be found in your country so that you can help your students identify what they find.

Students of all ages are usually quite keen to collect small animals, such as invertebrates (which include 97% of all known animal species), from the school playground or surrounding areas. However, you should point out to them that, although apparently insignificant, these are living creatures; they and their habitats must be treated with respect and consideration; e.g. any lifted stones must be replaced with great care. If pupils are going to collect creatures and bring them into school, you need to show them how to set up a temporary habitat for them in a suitable container such as a margarine tub or similar.

1. The environment should be quite moist and placing a small piece of rolled up damp tissue paper in the bottom of the tub will ensure this.
2. Placing a few leaves inside the tub is a good idea, preferably those of the plant or shrub near or on which the creature was found.
3. Each different type of animal should, ideally, be kept separate; slugs, for example, leave a trail of slime in their wake and other animals legs' may stick together if they are placed in a container with slugs.

Once they have transported them appropriately from home or the playground they should be transferred to a more suitable habitat within the classroom if a longer study is required. A large plastic or glass tank with leaf mould in the bottom together with a few stones will suffice. A piece of linen or muslin held in place by an elastic band or piece of string would serve as an appropriate cover. The animals should be returned to their natural habitat as soon as possible.

Equipment

Assortment of small jars, boxes and containers

Nylon netting or muslin, elastic bands

Hand lenses

Plastic or glass tanks

Cardboard boxes

Black plastic sheet or large piece of card

Old white sheet

Sheets of card

Small lengths of wood

Trowel (to dig in soft earth)

Clipboards

Paint brushes/plastic spoons (also for transferring creatures into the containers)

Methods of collection

There are several ways in which small creatures can be collected, which should not cause them distress.

1. Small paintbrushes can be used to ***very*** gently brush animals from leaves, tree bark, rocks, etc. into small containers.
2. Pitfall traps: these are small holes dug into the soil and filled with small containers, such as jam jars, so that the mouth of the container is just below the surface of the soil. In each container should be placed a few morsels of 'bait' to entice the creatures in. The container should be covered so that light cannot enter directly. Placing a few stones around the edge and covering the stones with an appropriately sized piece of card can achieve this. There should, of course, be sufficient space between the stones to allow the creatures' entry. The traps can be inspected daily to see what creatures have been caught.
3. Lay a piece of black plastic sheeting over the ground, say 1 square metre, early in the morning and see what creatures are under it towards the end of the day.

Main groups of invertebrates

You will need to research the invertebrates that live in your local area.

Organisation

The class can be divided up into groups of three or four. Each group can be given the task of collecting small creatures by one or more of the methods described above. Their task will be:

1. To identify each of the animals they collect.
2. To classify them into groups justifying why they have assigned each one to a particular group.
3. To gather evidence to support their classification in terms of the animal's structure and habitats.

Choice chambers

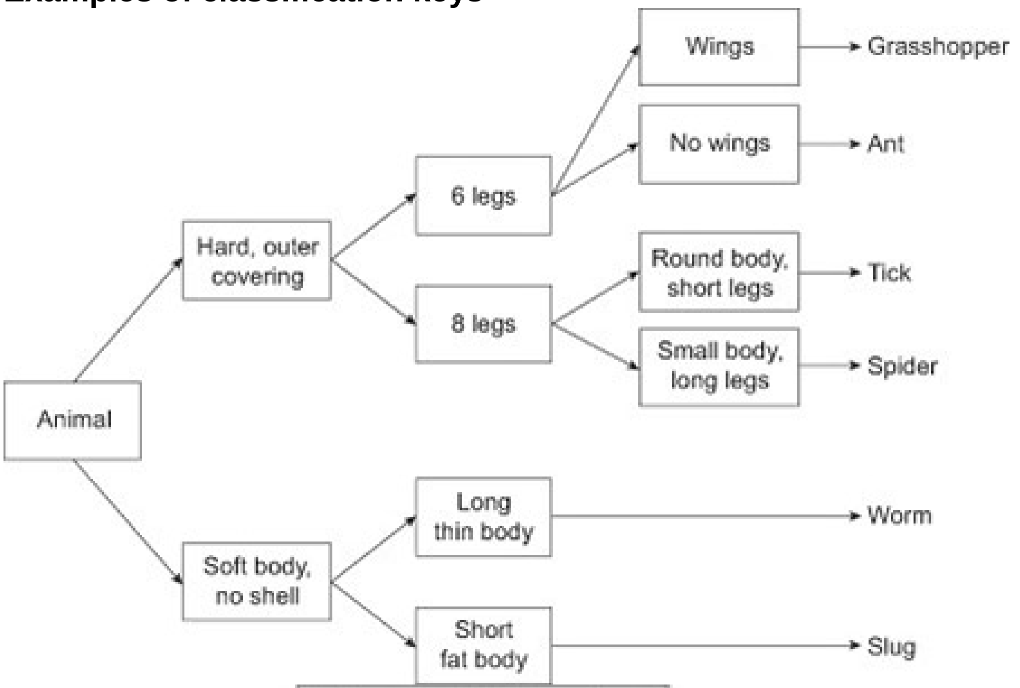
You could also carry out investigations into which types of environment each of the groups of animals prefer, e.g. light or dark, dry or moist, by constructing choice chambers. These are closed containers with several chambers, each of which comprises a different environmental variable, as suggested above.

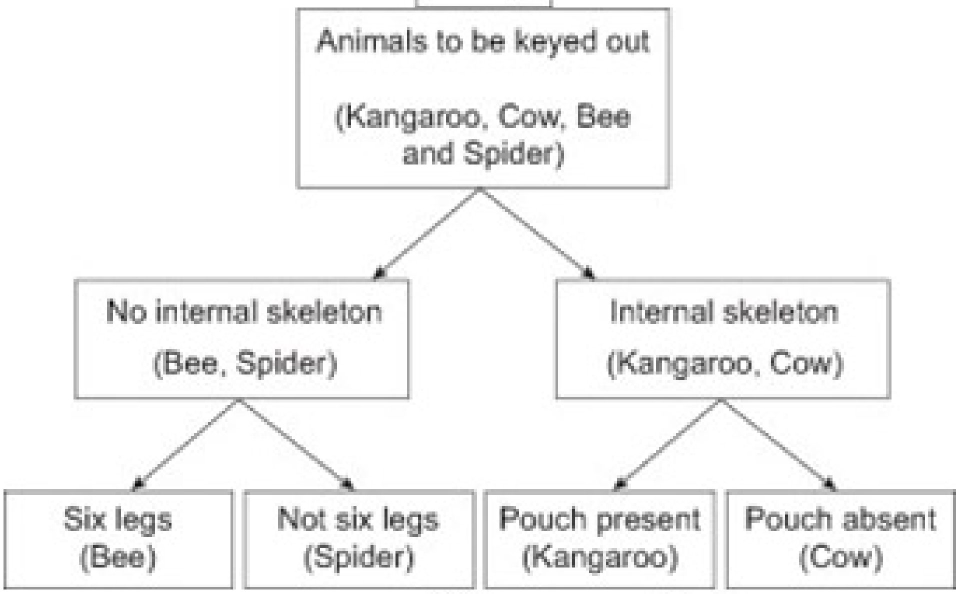
Setting up a dry environment will require the use of a desiccant such as silica gel. An example of a choice chamber is shown on the next page.

Resource 6: Examples of classification keys

Background information / subject knowledge for teacher

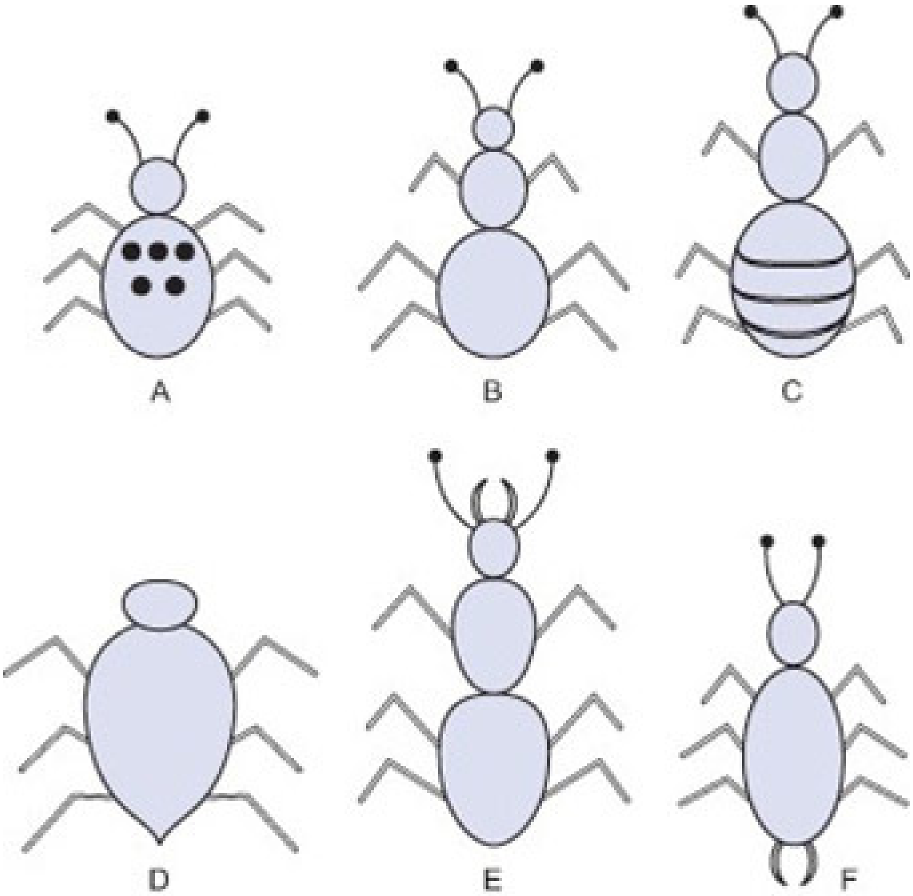
Examples of classification keys

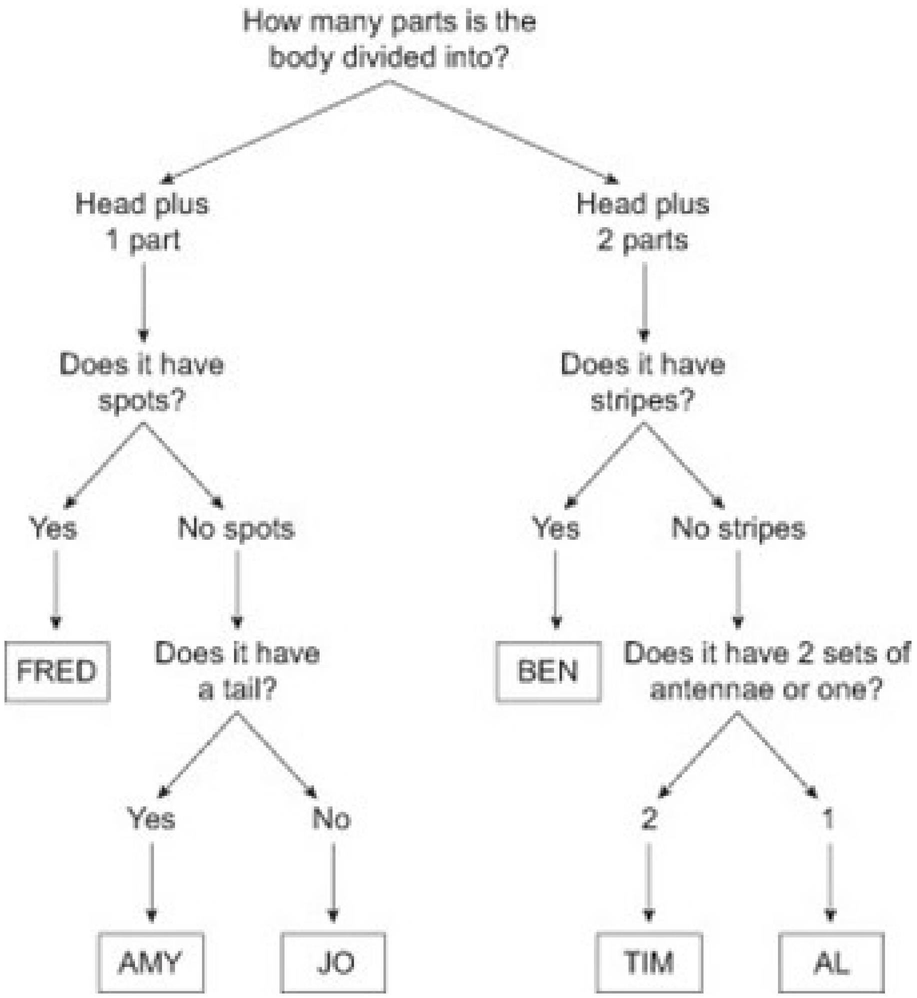




Six animals and a key that could be used with your students to illustrate how a key works

The students have to use the key to name each of the animals.





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Section 2: Transport

Theme: Making science practical

Learning outcomes

By the end of this section, you will have:

- used a demonstration practical as a stimulus to generate students' questions;
- used practical work to encourage students to observe carefully and to explain their observations;
- supported students in groups to plan an investigation.

Introduction

Practical work is a really important part of being a scientist and can help students to learn. There are a lot of different types of practical work including demonstrations; investigations in which students plan, carry-out and analyse their own experiment and experiments designed to help students learn specific skills or understand scientific ideas. Gaining first hand experience of materials, organisms and processes can increase understanding and help students to remember what they have been taught. Shared experiences and real objects may also be helpful for students who find English difficult. All practical work requires careful planning and some improvisation.

In this unit the activities are all linked to the topic **transport**. They involve students taking part in a practical demonstration, a practical activity designed to illustrate theory in which they are required to make very careful observations and an open-ended practical investigation. **Resource 1** has some general information about practical work and **Resource 2** has some background information to the topic.

1. Demonstrating transport in plants

Practical work is a very good way to engage your students with an idea or problem and help them to see the relevance of the theories that you want them to learn. As a teacher you will be keen to explain the scientific ideas. Often teachers are too ready to offer an explanation and miss the opportunity to really engage and interest their students. If you can show your students something that surprises or intrigues them, they will be keen to find out more. Sometimes, therefore, it is better to withhold information and let your students ask questions or suggest an explanation. In **Case study 1**, the teacher gets her students to set up an experiment but does not tell them why they are doing it. This is important; she wants them to think about what might happen and give them the opportunity to share their ideas. In **Activity 1** a slightly different way of presenting the same experiment is suggested.

Case study 1: Organising a demonstration

At the end of the topic on nutrition Mrs Ngnomo found that she had 15 minutes at the end of the lesson. The next topic she was due to teach was transport, and she had been collecting plants and flowers for a while. She got out her plants, some jars and some food colouring. She asked some of the students to half-fill the jars with water and to add a few drops of food colouring to each one. A pale coloured flower or a stick of celery was placed in each jar and they were left on the window sill of the classroom until the next lesson. The class were intrigued. Mrs Ngnomo gathered them round the front and asked them what they thought might happen. She did not tell them any answers.

She wrote all their suggestions on the board. Then she gave them five minutes to talk to each other. She asked each pair to write down a prediction and a reason for their prediction. She collected in their suggestions and kept them until the next lesson.

The next day the class rushed into the lab, keen to see what had happened to their flowers. The white carnations had gone blue and the veins could be seen all the way through the celery.

The students were really interested in what had happened and Mrs Ngnomo let them cut thin sections of the stems of the plants and look at them with a hand lens. She gave out the predictions they had made, gathered them round the front and asked them questions about the experiment. She started with simple, closed questions, based on their observations and moved on to harder questions that challenged their thinking.

Activity 1: Encouraging student questions

Set up a plant in a beaker of coloured dye. Choose a plant or flower that clearly shows the path of water through vascular bundles and that has a stem that you can cut easily with a razor. Your school text book should suggest suitable plants found in your area.

You should do this at the end of a lesson, so that the students can see what you are doing – but don't tell them anything about it. Leave it until the next lesson so the dye has time to move up the stem. (If you have not done this before try it beforehand to see how long it takes. If it is a long time until the next lesson, you might need to set up another one).

You should use probing questions aimed at helping students to predict, observe and explain what the experiment shows. You may also choose to show the same experiment with a plant that has a pale coloured flower where the dye is seen moving through the flower. Ask students to suggest what further questions this experiment raises. Write all suggestions on the board. Then ask students to predict the answers to their questions and to suggest how scientists could investigate these questions.

2. Organising a class practical

Demonstrations can be a good way to enthuse and interest your students, but they really begin to learn about being a scientist if they have the chance to do the experiments themselves. **Activities 2 and 3** describe two different approaches to class practical work.

Firstly, you can use experiments to illustrate key concepts and to help your students understand the theory, or secondly, you can support them in designing their own experiments in order to investigate a hypothesis. If you do this they will begin to learn about how scientists work as well as understanding the theory. In **Case study 2** the teacher does not have very much equipment but manages to do some simple experiments. Rather than get her students to copy notes about the experiments from the board, she uses a sentence matching exercise that will encourage her students to think about what the experiment has shown them. **Resource 3** provides ideas about how you can use students' writing to enhance learning. **Activity 2** shows what you could do if you have access to microscopes or balances or a source of heat. Firstly students are encouraged to look very carefully at something they see every day. Then, they put the leaves in special conditions to find out more and finally, they use a microscope to see something invisible to the naked eye. This illustrates three approaches that biologists use to build their understanding of the living world.

Case study 2: Doing practical work with limited resources

Mrs Ogina works in a secondary school near to a large city slum and has very few resources, but she is very resourceful. She is passionate about living things and her students love coming to her room because there are lots of plants growing in pots and pictures of living things that she has collected from old magazines and tourist brochures.

Before the lesson, Mrs Ogina had put a plastic bag over one of the plants in a pot. By the time the lesson began, droplets of water had collected in the bag. She gathered her class round the front and asked them where the water had come from. She didn't tell them the answer but was encouraged when someone suggested that it might be something to do with the leaves.

She sent them out of the classroom to collect leaves. She asked each group of five students to collect three different types of leaf. (She had also brought some in from where she lives as she knew there was not much variety near the school). She asked them to look at the leaves very carefully and to write down four ways in which they are adapted for photosynthesis. She asked them to think about what they all had in common and what the differences were between them.

When they had been working for a while she stopped them and went back to the suggestion that the water might have come from the leaves. She drew a diagram of a leaf on the board and explained about the stomata. She encouraged them to look carefully at their leaves and see where the stomata should be but explained that they would need a hand lens or microscope to see them.

The next lesson, Sam came rushing into the classroom to show Mrs Ogina a magnifying glass that his uncle had given him. He was happy for the students to take turns in looking for the stomata, provided they were careful with the magnifying glass. To finish the activity, Mrs Ogina wrote statements on the board (see **Resource 4**) and the students had to match them correctly to make sentences.

Activity 2: Encouraging careful observations

Organise the students into groups of three or four. Ask each group to collect four different leaves. Challenge the groups to find five adaptations for photosynthesis that they can observe without a microscope or hand lens.

Now give each group a beaker or tin of boiling water. Ask them to put each leaf in turn into the water, observe what happens on both sides of the leaf and explain what they see. They should notice that air bubbles appear at the lower surface of the leaf, showing that air is escaping through tiny holes.

Show them a diagram of a section of a leaf seen under a microscope and ask them to relate their observations to the diagram. If your school has a microscope you can show them the stomata or better still get them to make their own slides.

3. Planning investigations

Students enjoy planning experiments for themselves. In doing so, they develop thinking skills and the ability to ask questions, both of which will help them to learn. In order to plan an experiment, students need a question to answer or a hypothesis. It might be something like ‘which plastic bag is the strongest?’ or ‘which design of paper airplane flies the furthest?’

In **Case study 3** the teacher chooses a simple question that she thinks will interest her students. **Activity 3** describes an investigation linked to the topic of transport which involves thinking about where on the leaf the water is coming from. You will to need to lead them to the idea that spreading petroleum jelly on the surface of the leaf will prevent water from leaving, but leave the details of the plan to them. Use questioning to encourage them to think about how they will detect water loss, how they will decide on where the water is coming from, what the control will be and why they need a control. Some groups will need more help than others.

When students plan their own experiments, they don’t always come up with the best way of doing it, but that doesn’t matter because you want them to learn about the process as much as the theory. If you make sure that they evaluate their experiment carefully they will still learn and will be receptive to your suggestions of how it might be improved. The more investigations you do, the better they will be at doing them.

Case study 3: A simple investigation

Mr Machacha did an investigation with his class in biology. However, it was not a very successful lesson as his students found it very difficult – they were not used to designing experiments. They did not appreciate the importance of a ‘fair test’ or the benefit of testing their idea before they started collecting data. He realised that they needed the opportunity to do a really simple investigation that would help them to understand the principles involved in planning experiments.

Mr Machacha made two different paper helicopters (see **Resource 5**). He asked the class which one was the best. This got them thinking about how to decide what was ‘best’ and how to measure it. He got them to predict how the size of the rotors would affect the time it took to fall. He purposefully didn’t tell them how to do the experiment or how to record the results. They soon realised that they had to drop it from the same height each time and that they needed to think about how best to record the results.

His class spent about 20 minutes taking readings and plotting a graph. Mr Machacha went round asking them questions about how best to record the results and helping them plot a graph. At the end he asked the group who had done the best to draw their table of results on the board so everyone could see what they had done. They had a lot of fun and learnt a lot about how to plan experiments.

Activity 3: Investigating leaves

Tell the students that they are going to plan their own investigation into how water is lost from leaves. Ask them to predict whether more water will be lost from the upper or lower surface of leaves. If they have done **Activity 2**, ask them to think about what they observed when they put leaves in boiling water. Do not tell the answer to this, but ask them to work in groups to design an experiment to answer the question. You will need to give them some clues and prompts (see **Resource 5**) but should not give them more information than they need.

Collect the written plans. Check whether they are reasonable and collect apparatus to do as many different ones as possible. In the next lesson, give them feedback on their suggestions and allow students to set up all the ones that are possible.

Resource 1: Practical work

Teacher resource to support teaching approaches

Practical work

Introduction

Practical work is an important part of learning about science and learning to be a scientist.

The TESSA materials consider practical work in science involves pupils finding out, learning and verifying through observation and experiment, using skills and methods that are used by scientists in the real world. There are different types of practical work, which serve different purposes. Over time, a good teacher will make sure that their students experience different types of practical work.

Purposes of practical work

Different types of practical work and particular experiments will meet different objectives, but the benefits of practical work include:

- Developing practical skills and techniques such as how to use a microscope.
- Gaining first hand experience of materials, organisms and processes that may increase their understanding of science and help the retention of knowledge.
- Developing inquiry skills, such as control of variables, analysis and recording of data and looking for patterns.
- Motivation and enjoyment.
- Encouraging and promoting higher levels of thinking. Pupils can be asked to predict and explain when presented with problems and phenomena.
- Communication skills. Practical work may provide a context for the development of communication skills. The link to shared experiences and real objects may be very helpful for learners with limited proficiency in English.

Types of practical work

- **Demonstrations** – A teacher may decide to do a demonstration for reasons of safety or due to lack of time or resources. They may also be the most suitable method for consolidating understanding or providing challenge. Try to actively involve pupils through questioning or through participating in conducting the experiment or activities before or during the demonstration (e.g. predicting if statements are true or false and then using observations to confirm or change their decision).
- **Structured practical** – Pupils do an experiment in groups. The teacher may give them instructions to follow, advice on recording and analysis and questions to help them relate their observations to theory. These may be suitable for practising skills and techniques, supporting particular inquiry skills, and gaining experiences.
- **Rotating (circus) practical** – Pupils in groups move from one experiment to the next at ‘stations’ in the classroom. The experiments should be related and instructions should be brief. Similar questions at each experiment will help pupils

gradually build their understanding of a key concept, e.g. particle theory of matter or adaptation. Some of the stations may include a card sort or problem to solve rather than an experiment.

- **Investigation** – Pupils plan, carry out and analyse their own experiment. They may have freedom to choose what they investigate or the teacher may limit the materials available or specify a topic to investigate. The teacher has a role as a facilitator rather than teacher. They will usually give pupils guidance on 'the scientific method' or carrying out a 'fair test'.
- **Problem solving** – this is similar to an investigation, but pupils have more freedom of approach. It may be a practical problem, such as dropping an egg from the top of a building without breaking it, which can be solved in a number of ways. This can be motivating and a good vehicle for the promotion of communication skills.

Organising practical work

Whenever you are planning an experiment, you should try it out yourself before the lesson. Simple experiments are often more complicated than you might think. You will also need to do a risk assessment. This means thinking about the potential hazards and taking steps to reduce them.

When dealing with chemicals other than water, students should wear safety goggles. If safety goggles are not available, you need to use very dilute solutions (0.1 M). The chemical that is most likely to cause permanent eye damage is sodium hydroxide (above a concentration of 0.4 M).

You will need to think about how your students will get the apparatus they need. The things you might consider could include:

- Give them an activity to do at their desks and, while they are doing it, you distribute the apparatus they will need.
- Spread out the different items around the room and ask one person from each group to collect what they need. By spreading it out, you will avoid the potentially dangerous situation of lots of people gathering in the same place.
- Give out the chemicals yourself with a teaspoon on to small pieces of paper that they can take back to their place. This will ensure that they get the right amount and will avoid a lot of mess!

Resource 2: Transport in plants

Background information / subject knowledge for teacher

Transport in plants

It is amazing!

Plants include trees such as the giant redwood trees of California, USA. These trees are often over 100 metres tall.

Even these tall trees can transport many litres of water up their trunks in just a few hours on a hot day.

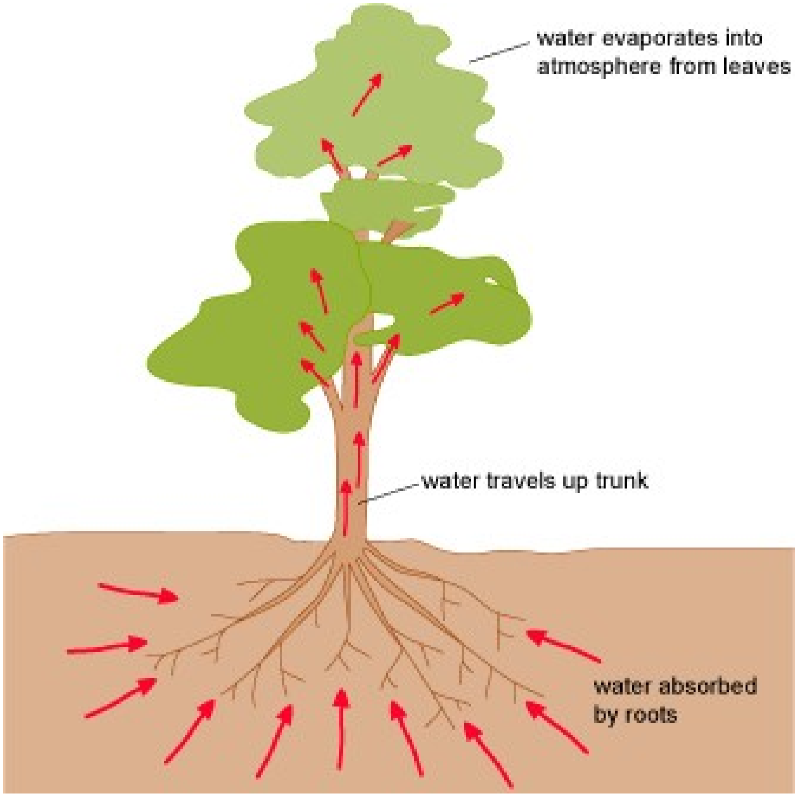


Diagram 1 Movement of water through a plant

What are the main substances transported by plants?

Water is transported from the roots through the plant and out through the leaves.

Mineral salts (ions) are transported from the roots to all parts of the plant.

Sugar, made in photosynthesis, is transported from the leaves to all parts of the plant.

Oxygen and **carbon dioxide** are transported through tiny holes (pores) on the surface of leaves and stems through a network of air spaces within the plant to and from all living cells.

What are the routes and mechanism of transport?

Water moves from the outer layer of the young roots to the centre of the roots, via cell walls and cytoplasm. It moves by diffusion and osmosis.

It then passes into the **xylem** cells. It passes up to the stem and leaves in the xylem in the transpiration stream.

Once in the stem and leaves water can pass out of the xylem to all the cells via the cell walls and cytoplasm, as in the root.

Mineral salts pass along the same route as water. They pass from cell to cell by diffusion or active transport. They pass up the xylem in the transpiration stream.

Sugar passes by diffusion from leaf cells to the **phloem**.

It passes from the leaves to the stem and root via the phloem. The mechanism for this is not fully understood.

Oxygen and **carbon dioxide** are transported through tiny holes (pores) on the surface of leaves and stems through a network of air spaces within the plant to and from all living cells.

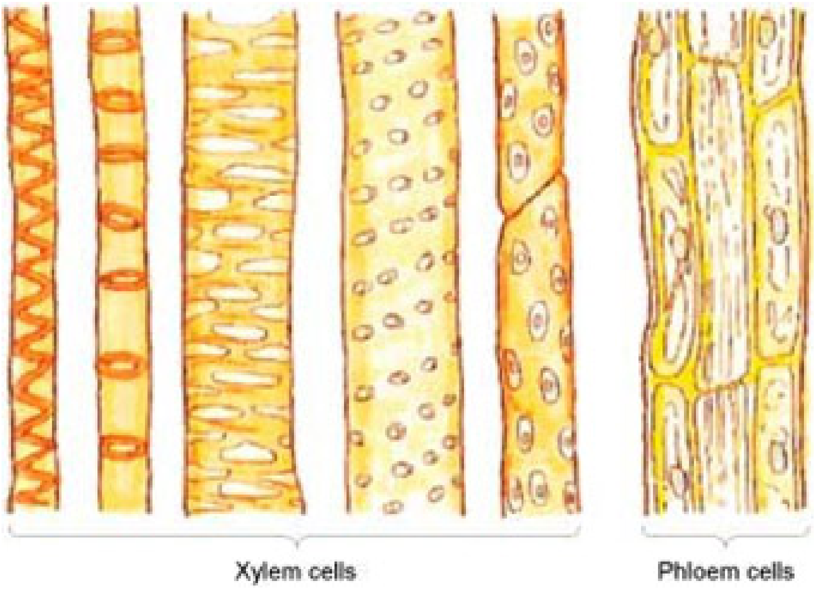


Diagram 2 Structure of xylem and phloem cells as seen under the microscope

The transpiration stream

Most of the water moving through the plant evaporates from the surfaces of the cells inside the leaves and escapes from the leaves as water vapour. The evaporation from the aerial parts of the plant is known as **transpiration**. The sun provides the heat energy for this evaporation to occur.

A continuous column of water extends from the outer surface of the cells inside the leaf through tiny spaces in the plant cell walls to the water inside the xylem vessels.

Because of its special **cohesive properties** (water molecules 'want' to stick together) water that has evaporated from the leaves is replaced by water drawn up through the xylem.

The water column at the bottom of the xylem in the roots is continuous with a water network in the walls and cytoplasm of the root cells all the way to the outer surface of the root.

Stomata

Stomata (singular, stoma) are found on the surfaces of leaves – also of stems and flowers. A stoma is a pore or hole. It is surrounded by two cells called guard cells. These guard cells can change shape and this alters the size of the pore, allowing the amount of water vapour, oxygen and carbon dioxide that can pass through the pore to be controlled.

Water uptake by the roots

Plant roots form a branching network in the soil. Uptake of water and mineral salts is mainly carried out by the ends of the youngest roots. Just behind the tips of the branches of the roots is a region of root hairs. These are formed as extensions of the cells in the outer layer of the root (root epidermal cells). These root hairs increase the surface area for absorption of water and minerals from the soil.

If the stem of a plant is cut at its base, water exudes from the cut stem. This suggests that a pushing force is generated in the roots – **root pressure**. Root pressure on its own is not enough to drive water to the top of the tallest trees.

Resource 3: Students' writing

Teacher resource to support teaching approaches

Students' writing

Getting students to write about their ideas is a good way to find out what they understand. Traditionally most of the writing that students do in science involves writing short answers to closed questions, or copying notes from the board. If this is all the writing that your students do, then you will be missing opportunities for them to demonstrate what they know and to be creative.

Writing in science should definitely not be restricted to answering questions and copying notes. There are a variety of ways in which you can use children's writing to probe their understanding, develop their knowledge and refine their skills and some of these are summarized below.

DARTS

This stands for Directed Activities Related to Texts. As the name suggests the activities involve pupils working with texts that have been changed in some way. One common device is text with words missing that pupils have to supply. The missing words can either be listed below, or not, depending on the abilities of the pupils.

Sentences that link together to explain a process or phenomenon can be jumbled up and pupils have to decide their correct order.

Learning diary

This is a useful way of helping pupils reflect on their learning and even evaluate it. They will need to be trained to do this as it usually does not happen naturally.

Word matching

You supply a list of scientific words and definitions. Students have to match the right word with the correct definition.

Poster production

Producing a poster will not only give pupils an opportunity to demonstrate their knowledge and understanding in writing but also enable them to use drawings and diagrams to illustrate science concepts

Leaflet production

This is similar to poster production but with the added dimension that it normally expresses a particular view or opinion. It is often useful to ask pupils to produce leaflets expressing a view that is opposed to their own.

Pressure group letter writing

This is similar to leaflet production but is just text written in continuous prose with the intention of expressing a usually strongly held view. This provides pupils with an opportunity to marshal their thoughts and to construct a persuasive argument.

Experiment write up

Encouraging your students to write about their experiments in their own words will show you how much they understand. A strategy that teachers often use is to provide some headings and some key words that their students should be trying to use so that they can structure their writing.

Concept map construction

This involves breaking down a complex idea, process or phenomenon into sub-components and linking them graphically to display their logical sequential relationships and how they contribute to an understanding of the whole. This is normally quite a cognitive challenge and requires a lot of practice to perform successfully. Probably more significantly it requires a sound knowledge of the subject if the maps are to make sense.

Summarising

Pupils have to decide on key points from an extract and either rewrite them to fit in with a restricted word limit or number of points.

Story boarding

Pupils illustrate a particular process by transcribing from text to a series of pictures in cartoon form that describe the process.

Using flow diagram

This is similar to storyboarding except that the main features or aspects of the process are represented by particular diagrammatic symbols either of your choice or your pupils'.

Resource 4: Understanding the structure of leaves

Teacher resource for planning or adapting to use with pupils

This resource can be copied for all students, or you can copy it on to the board.

Leaves

1. Look at the different leaves you are given.

   Read the statements a to e below.

   Write the statements in your book, leaving a clear line after each one.

   a. Leaves are flat with a large surface area
   b. Leaves have lines called veins on them
   c. Leaves are usually green
   d. The upper surface is darker green than the lower surface
   e. Leaves are thin

2. Complete your sentences using statements f to j below.

   a. to take water to all parts of the leaf.
   b. so a lot of sunlight falls on them.
   c. because there is more chlorophyll near the top of the leaf.
   d. because they contain chlorophyll to absorb light energy.
   e. so gases don’t have far to move.

3. Draw one of the leaves.

   Label the following parts:

   - Veins
   - Midrib (a big vein in the middle)
   - Blade (the flat part).

4. If you notice anything else the leaves have in common write it down.

Resource 5: Investigations

Teacher resource for planning or adapting to use with pupils

Simple investigations

In order to help their students learn about how to do investigations, teachers often choose a simple problem or question. Students can then concentrate on the investigation and not worry about the science.

Testing household products is popular, such as investigating which is the strongest bag for carrying groceries.

At the end of this resource is a template for a simple paper helicopter. Students can time how long it takes to fall from a height. They can change the area of the blades (by cutting them down) or change the mass by adding paperclips. In the process they learn about predicting, fair-testing, repeating readings, taking averages and spotting results that should be discounted.

To help your students plan a simple investigation you could write these questions on the board:

- What question are you trying to answer?
- What do you predict the answer will be and why?
- How will you measure … [the strength of the material, the time for the fall, etc.]
- What will you have to keep the same for each test?
- How will you record the results?
- How will you make sure the results are reliable? *[They may need prompting to repeat readings.]*
- What do you think the difficulties will be with your experiment? *[Encourage them to do some trials to test their method.]*

In an investigation like this the **process** is more important than the results. At the end gather your class round the front and use questions to draw out the important features of the process. Highlight the importance of making a prediction, testing the method, controlling variables, repeating the measurements, looking critically at the results and being prepared to ignore any where an error has been made. Once your students understand the principles of a scientific investigation, they will find it easier to plan an investigation to test a scientific question.

Leaf investigation

This is a simple investigation but it is important to let your students work out how to do it. Resist telling them the answers, but do ask leading questions if they are stuck.

You can tell them that rubbing petroleum jelly on a leaf will seal it and prevent water escaping.

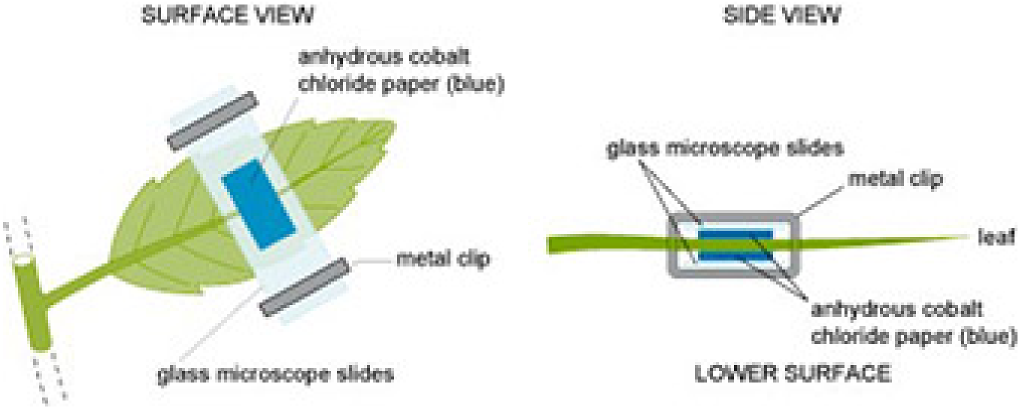
Let them work out how to test whether both sides of the leaf lose water, or whether one side loses more than the other.

Each group will need some leaves or access to a small plant in a pot.

There are two ways you can set this experiment up.

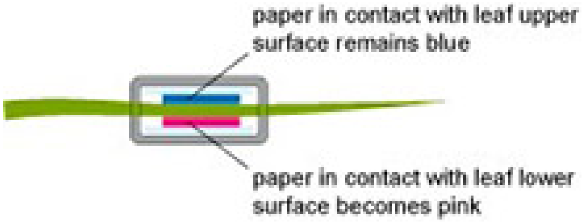
Experiment to show that more water is lost from the under surface than from the upper surface of most leaves

1. As many leaves as possible (preferably still attached to plants) are treated as shown:



Leave for several minutes.

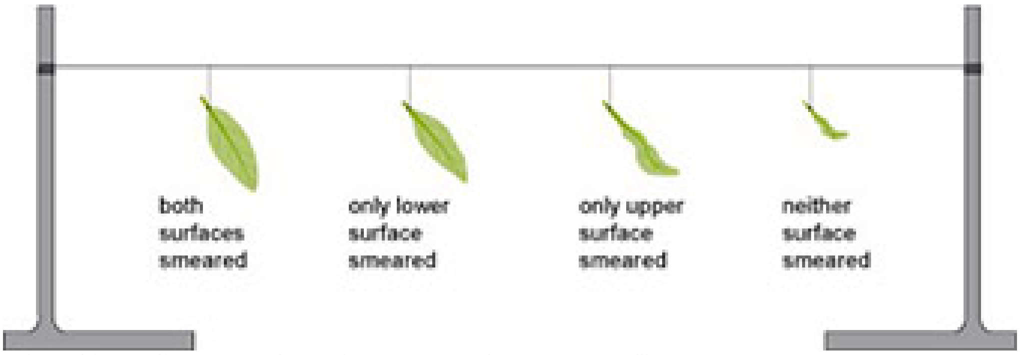
Result



1. A series of leaves have their surfaces variously smeared with petroleum jelly

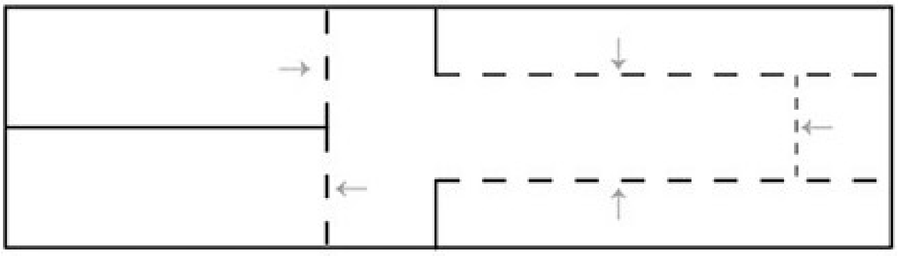
The leaves are left for a few days and observed at various intervals

Result

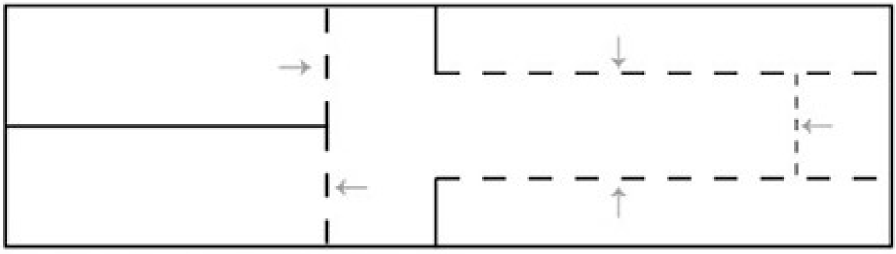


Adapted from: Life, Form and Function; Brewer and Burrow, Macmillan, 1972, p. 138

Below is a template for making a simple helicopter. Cut round the bold lines and fold the dotted ones.



Cut along solid lines. Fold along dotted lines.



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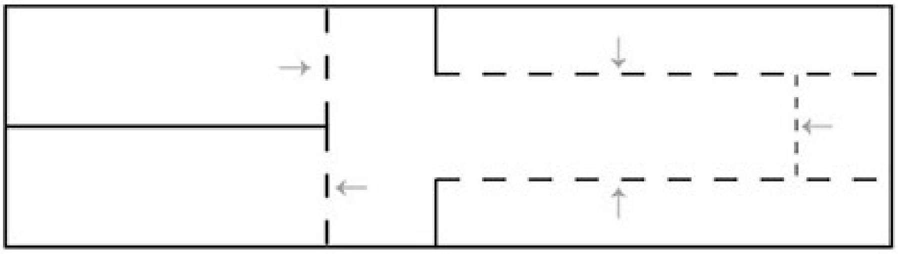

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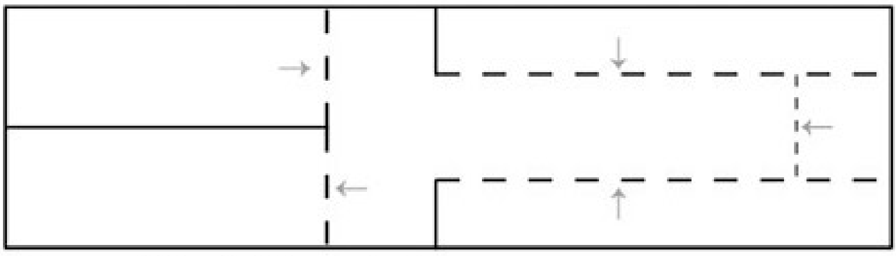

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Return to Science (secondary) page

Section 3: Respiration

Theme: Science lived – relevant and real

Learning outcomes

By the end of this section, you will have:

- helped your pupils to learn some science by studying the working of their own bodies;
- helped your pupils to collect data related to exercise and blood supply and record it appropriately and helped them to analyse and interpret patterns in this and additional second-hand data;
- taken pupils to visit a local industry to see how knowledge of respiration and microbial activity is applied.

Introduction

Science is all around us. Too often young people see science as something learnt from a textbook that is not relevant to their everyday lives. An effective way of demonstrating that this is not the case is to start with the everyday context and use it to draw out scientific principles. Activities like baking cakes, growing vegetables, and mending a bicycle all involve scientific principles. Making connections between the things they do at home and the science they learn in school can help to reinforce the scientific principles that your students need to learn. Asking students about things outside school that are important can get them engaged and interested – especially if some controversy is involved. Most real-life situations are actually quite complicated and it is easy to find yourself talking about chemistry, biology or physics, or even wider issues. This will help to keep your students interested in science and help them to see how science can help them to understand the world.

Resource 1 gives some strategies that you can use in order to help your students make these connections. We want to encourage you to develop the habit of relating all the areas of science that you study with your students to their everyday lives. Try to refer to the list in Resource 1 whenever you start planning a new topic for your pupils and ensure that you incorporate some of the ideas. In this unit we demonstrate how you can use some of these ideas in the context of learning about **respiration.**

In this unit we start with aspects of science relevant to the students' own bodies and their experiences at school, home and in their leisure time. We then move on to consider issues of wider importance to their own lives and to society as a whole.

1. Measuring changes in pulse rate

In biology one of the best ways of making students see the subject as relevant to them is to relate it to their own bodies. In **Activities 1** and **2** they consider the way their bodies respond to increased exercise. When you introduce the topic, you should be able to refer to their participation in physical education (PE) and school sports. They should be able to draw on their own experience in class discussions of the activities. **Activity 1** is a standard practical that the students will enjoy, especially if you are able to take them outside to do the exercise. By asking them to design their own table you are helping them to develop an important skill – communicating experimental results clearly. They may need some assistance with this. Make sure you have worked out a suitable table yourself, so that you can help them if they have any difficulty. A traditional way to explain these results might be to discuss them as a class and to give them notes summarising the processes that occur during exercise. The written exercise replaces the notes and gives them practice in writing a clear concise paragraph about scientific ideas (an important skill for exams). It is designed to give the students enough help to work it out for themselves. You should discuss the results as a class before asking them to do the writing, but let them do the writing themselves.

Case study 1: Organising groups to do an experiment

Mrs Addai had explained the terms pulse and pulse rate and shown her students how to measure their pulse. She planned a practical in which her students investigated changes in their own pulse rate, in beats per minute, before and after exercise. She had a stop watch on her mobile phone and two egg timers. Before they started, they practised measuring a minute by counting slowly to sixty. This was necessary so that those without a timer could still do the experiment.

She divided the class into groups of three or four with each person performing a specific task: one person in each group acted as the subject; another took the pulse of the subject; a third did the timing and the fourth recorded the results in the table. The third and fourth task could be combined. The students could change tasks, so that everyone had a chance to have their pulse measured. Mrs Addai noticed that last time they did an experiment, the boys did the practical work and the girls tended to hang back. This time, she insisted that they worked in groups of boys or girls. They started by measuring the pulse rate of the subject while he or she was sitting down comfortably. They then had to run either outside or on the spot in the classroom for two minutes. Their pulse rate was measured again immediately afterwards.

At the end she gathered them round the front to discuss the significance of the changes in pulse rate before and after exercise and the reasons for variation in rates between individuals. For their homework, Mrs Addai asked the students to make a poster outlining the investigation and highlighting the key results. She told them what they had to include in the poster (what they did, why they did it, what they found out and what it showed) but let them choose how to present their work. She was amazed by the creativity and enthusiasm that they showed.

Activity 1: Investigating pulse rate

You could do this activity when you have taught your students the principles of respiration; or you could do the experiment first and then use the results to help you explain respiration. Think about what would work best for your class. Divide your students into groups of three or four. Explain what they are going to do and ask them to design a table in which to record their results. Tell them they are going to investigate the effect of exercise on pulse rate and describe what they should do. They will measure the pulse rate (pulses per minute) for each person in the group at rest (sitting down). They should then walk for 30 seconds before taking the pulse again. They should repeat this after running.

They could exercise by walking or running on the spot, but, if you can, take them outside to do this. After they have finished, if you have already explained respiration, ask them to write a paragraph describing their results using the following words and phrases: average; differences between individuals; increase heart beat; oxygen; muscles; respiration; rate; energy.

2. Focus on interpreting data

Scientists need to be able to identify patterns in experimental data. This can be a complex skill and students may face difficulties doing this in exams if they have not practised it beforehand. In **Case study 2**, the teacher shows her students examples of how data are presented in the media. It is a good idea, as a science teacher, to keep a file of cuttings from newspapers or magazines that you can use with your students. Any story related to science is worth keeping – you never know when it might be useful. Sometimes, newspapers present data in a particular way to make a specific point. Your students need to learn to be critical about what they read or hear. In the main activity, students are given the data in graphical form, but you could show them the graphs and the tables and get them to decide on the best way to display the data.

Case study 2: Explaining patterns in data

Mrs Maduhu had prepared a poster of graphs, charts and tables cut out of newspapers and magazines to show her class that these ways of presenting information are commonly used in many situations in daily life as well as in science, and science examinations. The ways of presenting the data included tables, line graphs and pie charts. She told her students that it was important that they became familiar with reading graphs, charts and tables and looking for patterns in the data so they could understand and explain what these forms of presentation showed. She also showed them how easy it is to emphasise a particular point by changing the scale on a graph.

Mrs Maduhu wrote three tables on the chalk board with data about cardiac output (**Resource 4**). She asked her students to copy the tables into their science books very carefully, to study the tables for their homework and to look for patterns in the figures.

She also asked them to use their knowledge of respiration to explain each pattern. For students who had time and were interested, she said they could do the same for Table 3. Next lesson, she put the students in groups of four and asked them to share their ideas. They had to choose one pattern they all agreed about, together with its explanation, and present this to the whole class.

Activity 2: Explaining patterns and peer review

Divide the class into groups of three to five students. Hand out a copy of the data on cardiac output and blood distribution to each group (**Resource 3**). If you do not have access to a copier, use **Resource 4** and write the information on the chalkboard. Tell them to write three sentences that describe patterns in the data on a sheet of paper. Give them this example to start them off: 'The amount of blood going to the brain stays almost the same during exercise.' Tell them to pass their sheet to the next group, who should decide whether they think each statement is correct. If it is correct they should try to explain the reason for the pattern, using their knowledge of respiration and exercise. They should hand the paper on to a third group for checking. Each group should be asked to read to the class one of the patterns and the explanations written by their neighbours.

You can round off the lesson by reviewing two or three of the key patterns reported and their explanations. You can point out any important patterns that have not been reported on and you can congratulate your class on their developing analytical and interpretative skills.

3. Baking and brewing

All living things respire and the respiration of yeast forms the basis of the brewing and baking industries. **Case study 3** and **Activity 3** show how you can make use of this in your classroom. In the case study, the teacher gets a visitor into the classroom and the activity involves a visit. While it requires time and careful planning, a visit to a local industry (e.g. bread making) will have real value in motivating students and in helping them to understand the relevance of what they do in class to the real world. It should also help them to realise that ordinary people have used aspects of the scientific process to refine their methods. Over hundreds of years scientists have observed, carefully experimented with different methods, evaluated the results and where necessary modified their methods. Before you go, try to prime students on what they should look out for. It will help if they have studied yeast and fermentation before they go and are asked to relate what they see to what they have learned.

Case study 3: Inviting a visitor to school

One of Mr Nkala's former students, David, had started working in a local bakery. Mr Nkala asked David to come and talk to his students about work in the bakery. David enjoyed his job and was pleased to do this.

He explained that the main ingredients of bread are flour, yeast, and water. He had brought some fresh yeast and some dried yeast to show the students. He put some of the yeast in a small bowl, added some warm water and a small spoonful of sugar. He asked the students to keep an eye on the mixture to see if they noticed any changes. In the meantime, he explained how to make bread.

David told the class that yeast is a single-celled fungus. Like all living organisms, yeast gets its energy during respiration. He asked them what they knew about respiration and was impressed with the replies. Yeast can respire without the need for oxygen (anaerobic respiration). As it respires yeast produces carbon dioxide gas and alcohol.

By now the students had noticed that the bowl of yeast, water and sugar had started to froth up with lots of tiny bubbles. David had brought some samples of the bread he made which he passed round for the students to examine. He asked the students why the bread did not taste of alcohol. Before he left, David explained what qualifications he had and described the training he had received. One day he hopes to own his own bakery and intends to specialise in making different kinds of bread from other countries. He gave the class a recipe for making bread (**Resource 5**) which they could do at home.

Activity 3: Organising a visit

Set up an experiment to show that yeast, sugar and water produce carbon dioxide and ethanol, provided that they are kept in a warm environment, in the absence of air. Explain to your students how this process is used in bread making and in brewing.

Try to arrange a visit to a local bakery or brewery, to reinforce learning and demonstrate the practical uses of this process. Depending on the size of your local bakery or brewery, there may not be enough space for the whole class to go on the visit. Those who do go could give a short presentation to the rest of the class when they return. You and your students will need to be

aware of strict rules on cleanliness and hygiene associated with any business concerned with food. You can ask your students to look out for ways the bakery workers ensure that cleanliness is maintained. Some equipment and processes could cause injury to your students, such as the hot ovens, so it is important that they act responsibly and listen to instructions carefully. During the visit students should try to find answers to a number of questions. Possible questions, together with suggested answers are included in **Resource 6** . Students should also be encouraged to think of and to ask questions of their own.

Resource 1: Making Science relevant

Teacher resource to support teaching approaches

Making science relevant to everyday life

Introduction

The TESSA resources are underpinned by a view that science is not just an activity that is carried out by people in white coats in a laboratory. Science helps students to make sense of the world and they need to realise that it is taking place all around them. Many everyday activities involve scientific principles. It is important that pupils get the opportunity to apply their scientific knowledge to an understanding of their own environment and that they understand that the skills they develop in science are relevant to some of the problems they face in everyday life.

Possible strategies

Class discussion

Use local examples where possible, but also encourage pupils to draw on their own experience in the classroom.

Practical work

- Use local examples and materials, e.g. hibiscus indicator; local minibeasts for work on classification or adaptation; wood and kerosene to compare calorific content of fuels.
- Give pupils a challenge using scrap materials, e.g. obtain clean salt.

Research projects

Pupils could find information from local newspapers or magazines or interview adults in the community, such as brewers, mechanics or health workers. This could be the basis of a poster, oral presentation or role play.

Making use of the school grounds

Besides the obvious opportunities for ecological investigations, the school grounds are a source of teaching examples in other topics such as corrosion, structures and forces. Take pupils to see them or ask them to find examples or collect data for analysis.

Day visits

Visit local industries, agricultural sites or museums. The effective teacher will link this to classroom work both before and after the trip.

Homework

Ask pupils to write about examples of science around them (e.g. chemical change in the kitchen or forces on the football field) or to bring materials to the classroom.

Writing tasks

Use local issues as a stimulus for creative written work, e.g. a letter to a newspaper or radio script on local environmental or health issues.

Discussion tasks

- Interviews – one child could be the 'expert' and the interviewer can ask questions as if they were producing a news item for the radio.
- Pupils come to a decision about a local issue, e.g. health promotion or energy supply.

You should create a file for yourself and keep any newspaper and magazine articles that you find that contain or are about scientific issues. Every time you start a new topic, ask yourself how it relates to everyday life and help your students to make those connections.

Brainstorming

Brainstorming as a class or in smaller groups can help students to make connections between the science they learn in class and their everyday lives.

Resource 2: Experiments on pulse rate

Background information / subject knowledge for teacher

Practical hints on measuring pulse rate

Investigating the effect of exercise on heart rate/pulse rate

You can find out how fast your heart is beating, that is your heart rate, by feeling your pulse. The wave of pressure which passes down an artery as a result of each heart beat is felt as a pulse when an artery is near the surface of the body and runs over a bone.

Finding the pulse

You can find the pulse in your wrist by turning your hand palm-side up. Gently place the middle and index finger of your other hand on the inside of the wrist at the base of the thumb. Press your fingers down in the groove between your middle tendons and your outside bone.

Do not use your thumb to feel the pulse as it has a pulse of its own.

You can also use a pulse in your neck region. To find this pulse, place your fingers gently on one side of your neck, below your jawbone and halfway between your main neck muscles and windpipe.

Do not press too hard when measuring your pulse.

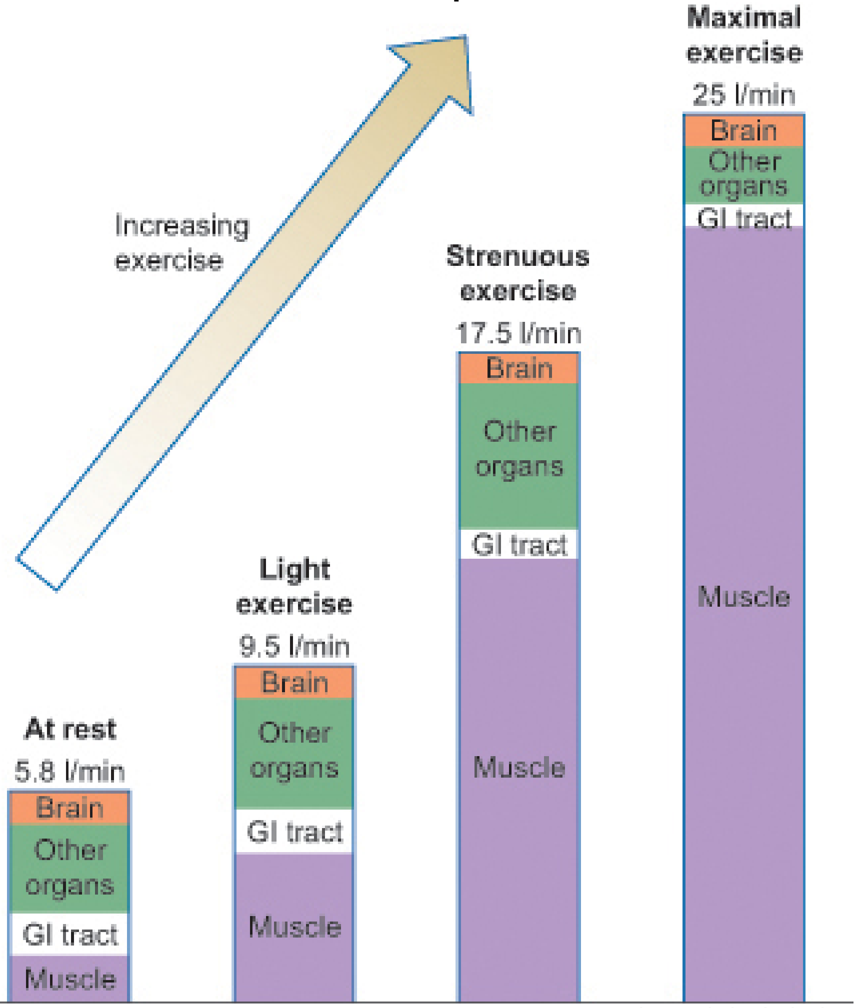
Extension investigation on the effect of exercise on heart rate/pulse rate

For an extra investigation, some groups could choose one pupil to be the subject. The subject should then do two minutes of exercise again. Their pulse rate is measured immediately after this as before and then at one minute intervals until the pulse rate has returned to the resting rate. The fitter a person is the quicker the rate will return to normal.

Resource 3: Data on the effect of exercise

Teacher resource for planning or adapting to use with pupils

Effect of exercise on cardiac output and blood distribution



Adapted with permission from Honeybourne, J. Hill, M. and Morrs, H. *Advanced physical education and sport for A level*, Cheltenham, Nelson Thornes.

Resource 4: Data pulse

Teacher resource for planning or adapting to use with pupils

Cardiac output data

Table 1. Changes in cardiac output under different exercise conditions

Condition	Rest	Light exercise	Strenuous exercise	Maximal exercise
Cardiac output l/min	5.8	9.5	17.5	25.0

Table 2. Distribution of blood (in l/min) to different parts of the body under different exercise conditions

Body area	Brain	Other	Gastro-intestinal	Muscle	Total
Rest	0.9	2. 4	1. 2	1. 3	5.8
Light exercise	0.9	2. 9	1. 3	4.4	9.5
Strenuous exercise	0.7	4.0	0.7	12. 1	17.5
Maximal exercise	0.7	1. 8	0.5	22. 0	25.0

Table 3. Distribution of blood as a percentage of cardiac output to different parts of the body under different exercise conditions

Body area	Brain	Other	Gastro-intestinal	Muscle	Total
Rest	16	41	20	23	100
Light exercise	9	31	14	46	100
Strenuous exercise	4	23	4	69	100
Maximal exercise	3	7	2	88	100

Resource 5: Making bread

Teacher resource for planning or adapting to use with pupils

Recipe for making bread

700 g (1½ lb) strong plain flour

15 ml (1 tablespoon) salt

15 g (½ oz) butter (for greasing the tin)

425 ml (3/4 pt) lukewarm water

15 g (½ oz) fresh yeast, or 10 ml (2 teaspoons) dried yeast with 5 ml (1 teaspoon) sugar

Method

Stir fresh yeast into the water or mix dried yeast and sugar with a few drops of water and add to the rest of the water.

Sift the flour and salt into a bowl. Make a well in the centre and add the water and yeast. Mix well until the dough comes away from the sides of the bowl.

Knead the dough with your hands for 10 minutes.

Put the dough into the bowl and cover with a damp cloth. Leave it for an hour in a warm place until it has doubled in size.

Knead the dough again for a few minutes Place the dough into a greased loaf tin or shape into balls and place on a baking tray.

Let the dough rise again in a warm place for another hour.

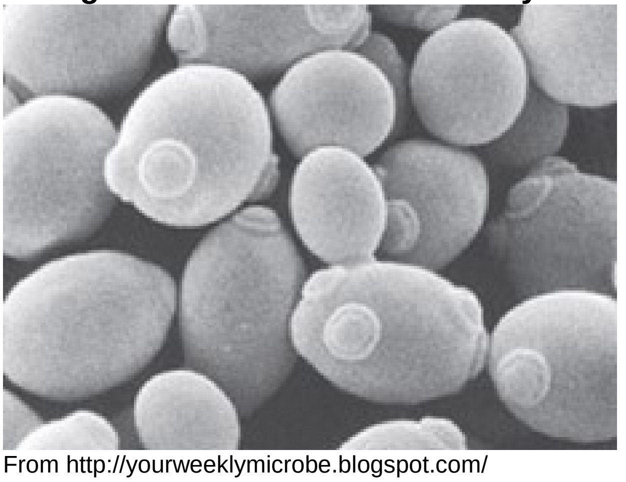
Bake the dough for 30–35 minutes in an oven at 230˚C (450˚F) or gas mark 8.

Resource 6: Background information on yeast

Background information / subject knowledge for teacher

Yeast and baking

Background information for bakery visit



From http://yourweeklymicrobe.blogspot.com/

Scanning micrograph of yeast cells.

There are many types of yeast. The species of yeast used in baking is known as ***Saccharomyces cerevisiae.***

Yeast cells are globose to elongate in shape. They are found in soils and on plant surfaces and are especially abundant in sugary media such as flower nectar and fruits.

Yeasts are saprophytes and feed mostly on sugars in the medium around them. Saprophytic organisms feed by secreting digestive enzymes on dead organic material and absorbing the products of digestion.

Yeasts reproduce by budding. During this process a small bump, the bud, protrudes from the parent cell. This enlarges and matures. The bud eventually breaks away from the mother cell to form a separate daughter cell. Some of the yeast cells in the photograph above can be seen with buds on them.

The production of alcohol by yeast is exploited in wine and beer making. *Saccharomyces cerevisiae* is most commonly used, but other species are important for some types of beer.

Several yeasts have been used in scientific research into genetics and cell biology. In 1996 *S. cerevisiae* was the first eukaryote to have its DNA fully sequenced as part of the Genome project.

Other species of yeast, such as *Candida albicans*, are pathogens and can cause infections in humans.

Notes on constituents of bread making

Amylase enzymes in the moistened flour convert the starch in flour to glucose, which the yeast cells use as their respiratory substrate.

Flour protein, called **gluten**, helps make the dough stretchy (elastic and plastic). This helps to ensure that the carbon dioxide remains trapped as it enlarges the bubbles within the dough. Kneading the dough changes the structure of the proteins in the flour, making them more elastic so the bubbles of gas are trapped. This makes the bread light and chewy.

Types of flour: strong flours contain plenty of gluten, but very little α-amylase enzyme. Wholemeal flour is rich in α-amylase.

Ascorbic acid (vitamin C) may also be added as a flour improver. It makes the dough more elastic and better at trapping gases and as a result reduces the time required for leavening. This is an important consideration in commercial bread production.

Potassium bromate is sometimes used as a flour improver.

Salt is often added in the bread making process. It inhibits the action of proteases (protein digesting enzymes) and so prevents gluten from being weakened into a sticky mass that cannot retain carbon dioxide.

Excess salt forms strong ionic bonds with side chains of protein molecules. This makes them less stretchy and leads to tough bread. **Excess salt** also inhibits yeast growth.

Questions about yeast.

Q1 Where do you find yeasts naturally?

A Yeasts are found worldwide in soils, on plant surfaces and in the atmosphere. Yeasts are especially abundant in sugary mediums such as flower nectar and fruits.

Q2 When did people first learn about yeast and how it could be used in bread-making?

A Yeast is probably one of the earliest domesticated organisms. People have used yeast for fermentation and baking throughout history. Archaeologists digging in Egyptian ruins found early grinding stones and baking chambers for yeasted bread, as well as drawings of 4000-year-old bakeries and breweries. In 1680, the Dutch scientist Anton van Leeuwenhoek first observed yeast cells under the microscope. At the time he did not consider them to be living organisms. In 1857, the French scientist Louis Pasteur proved that alcoholic fermentation was caused by living yeast cells.

Q3 How is yeast produced commercially now?

A Yeast is grown in a medium of sugar beet or cane molasses in large batch culture vats (50 000-200 000 litre capacity). Yeasts can grow in the presence or absence of oxygen.

The commercial production of yeast occurs in **aerobic conditions**. These conditions allow maximum multiplication of yeast cells. If multiplication is too rapid, oxygen levels fall and respiration becomes anaerobic. Hence oxygen levels must be monitored.

(N.B. When baking bread, the yeast in dough must be allowed to respire **anaerobically.** There is very little cell multiplication. Instead, the sugar is used mainly to produce alcohol and carbon dioxide).

After removal from the vats, the yeast is centrifuged and washed several times, then chilled to 2–4˚C.

Water is removed by dehydrators and the yeast packaged.

Fresh yeast

From http://en.wikipedia.org/wiki/Baker's_yeast *(Accessed 2008)*

Dried yeast

Q4 What special conditions are required for yeast growth and multiplication?

A Yeast must be grown under aerobic conditions in order for the cells to multiply. Hence oxygen must be supplied and levels must be monitored carefully.

Ammonium sulphate, $(NH_4)_2 SO_4$, is often added as a source of nitrogen for the yeast cells.

The pH must be kept in the range 4.0–5.5. As the yeast cells use up ammonium ions from the ammonium sulphate in order to get nitrogen, this tends to create acid conditions. This must be adjusted by periodic addition of alkali to keep the pH in the correct range.

Other substances may be added to aid growth, e.g. biotin or pantothenic acid.

The temperature must be kept at 30–35˚C to ensure reactions work most efficiently. Enzymes in the yeast cells are essential for respiration to happen. Enzymes are very sensitive to temperature.

Q5 How big is a yeast cell?

A The typical yeast cell is approximately equal in size to a human red blood cell and is spherical to ellipsoidal in shape. Because of its small size, it takes about 30 billion yeast cells to make up to 1 g of compressed baker's yeast.

A yeast cell is around 5–10 micrometres (μm) by 4–8 micrometres (μm).

There are 1000 micrometres in one millimetre.

The very sharp point on a pin is about 100 micrometres (μm) across.

Q6 What is the most important difference in the growth conditions for the production of yeast cells and the use of yeast cells in baking?

A The production of yeast cells occurs in **aerobic conditions**, so oxygen must be supplied. For baking, no oxygen should be supplied and the yeast must be allowed to respire **anaerobically.**

Q7 What is the meaning of the scientific name of bakers yeast, *Saccharomyces cerevisiae?*

A *Saccharomyces* means sugar loving. The species name, cerevisiae, comes from the name Ceres, the Roman goddess of agriculture.

Return to Science (secondary) page

Section 4: Nutrition, conservation and ecology

Theme: Problem solving and creativity

Learning outcomes

By the end of this section, you will have:

- told a story about problems in a local area and given students the opportunity to work out the reasons for the problems and to suggest a sensible course of action;
- supported students in using their knowledge of nutrients to plan a day's diet;
- organised students into groups to conduct research within their community and present it to the class.

Introduction

When your students start to look for a job, the qualifications that they have will obviously be very important. However, potential employers will also be looking for people who are creative and who are able to solve problems; they will be looking for people who can think for themselves. Students can sometimes view science as a subject that provides absolute answers that lead to technological advances which can be used directly to solve practical problems. In reality, many problems have cultural and economic perspectives that must be considered as well. Scientists must consider all perspectives when seeking solutions which will be successful in the real world. They need to be creative and able to work effectively with others. The case studies and activities in this unit are designed to show you how you can give your students the opportunity to be creative, to develop their thinking skills and to work effectively with others. They will fit into your normal teaching of nutrition, ecology and conservation. Some general strategies are given in **Resource 1** .

1. Using a story to think about local issues

Working effectively with others entails listening carefully to what they say. You need to respect, and also critically analyse, their knowledge and opinions. Students should be able to present their own knowledge and ideas in a clear and honest manner. They need to learn to work together to come up with solutions acceptable to all. There should be give and take on all sides. This is an important and difficult skill to acquire. Students will become more proficient at it the more they practise it.

In **Activity 1** and **Case Study 1**, we ask students to consider the possible benefits of applying their knowledge of ecology and conservation to a real problem. However, they also need to take into account the views of people who may be resistant to change. They not only need to look for ways to persuade local people of the benefits of change, but should also consider whether the local community may know of factors that scientists have not considered. **Case study 1** shows how one teacher used the story to revise certain topics. The activity uses a story to create interest and then a table to record key points.

Case study 1: Using a story to make revision fun

Christina Majula has a dilemma. She is keen to show her students that what they learn about ecology and conservation in school is very relevant to the daily lives of us all. She also wants the students to do well in their exams but is struggling to finish the syllabus. She plans a revision lesson which includes a story (**Resource 2**) to illustrate a real problem which biological knowledge and understanding could help resolve. Christina has prepared five posters which she will use as a circus of activities with her class. The posters will act as revision of the topic she has just covered with the class. Each poster provides information relevant to the problem (**Resource 3**). Christina reads the story to the class. She then divides the students into five groups. Each group has 10 minutes to look at each poster. She asks them to read the information and to note down some advice to the villagers with an explanation of why that would help solve their problems. She then gathers her students around the front and asks each group to report on what they have learned from one of the posters. Finally, she asks them to imagine that they were Kabwe. How could he convince the village headman that the ideas they were suggesting would work? He is young and new to the area, whereas the village headman is held in great respect. People are not likely to listen to what Kabwe has to say. The students became very animated and interested in a problem that some of them recognised.

Activity 1: Using a story to highlight a controversial issu e

Tell the students you are going to read them a story about a village with problems. Ask them to note down the problems the village has faced, while you are reading. Read Kabwe's story (**Resource 2**) quickly. After you have done this ask the students to tell you about the problems the village faced. They should have noted the lack of wild fruits, the poor harvests, low rainfall and lack of water (see **Resource 2**). Now put a table on the board with two headings: Kabwe's views; Chanda Bwalya's views. Ask students to take turns to read a paragraph and after each paragraph, add points to the table. Then organise them into groups and ask them to produce a poster suggesting ways of improving the situation. They should use their knowledge of science to suggest some solutions, but they should also think about who they would consult to help them and how they will convince the headman and villagers to adopt their ideas.

2. Thinking about nutrition

As you know, there is a lot to learn in science. You will find that if you can present the information in the form of a problem or issue, then it will be much more interesting for the students – much better than simply copying notes or listening to a lecture. In **Case study 2** and **Activity 2** we apply this idea to nutrition. Your textbook will explain the need for a balanced diet and give examples of foods rich in particular nutrients. In this activity, we ask students to create their own menu for a day. Students will enjoy the opportunity to make their own decisions about what they could eat and to compare these with their friends' choices. They will also reinforce their knowledge of the basic ideas and terminology of the topic. The case study shows how one teacher used this as an opportunity to differentiate the work. (**Resource 4** has more information on catering for students with different abilities). Just as with **Activity 1**, students will apply their scientific knowledge to a practical problem with a wide range of possible answers. A key aspect of the problem-solving approach is the development of the students' ability to think for themselves and to find and justify an answer that is unique. This helps students to realise that success in science is not simply a matter of learning and remembering facts from a textbook.

Case study 2: Differentiating work

Mrs Kaddu is teaching nutrition to her students. She knows that it is important that the whole class knows the main types of food required for a healthy diet. She also knows that some of the students in the class are particularly able. She decides to set two different tasks for students, depending on how easy or difficult they find science. This will help maintain the interest of the students who find science easy and extend their abilities. She uses **Activity 2** but also prepares some extra materials. These include two tasks that will challenge the more able students to use detailed nutritional information and provide them with an opportunity to practise their numeracy skills. She gives these students information on the energy content of foods in kilojoules and gives them values for the energy requirements of an active teenage girl and boy. She also gives them information on the energy needed for different types of activity. This provides a range of possible extension work. All the students in her class have work that is suitable for their current stage of development and ability. You can see the extension work Mrs Kaddu made in **Resource 5** .

Activity 2: Working in groups to learn about nutrition

Organise your students into groups of three to five. Ask them to use the textbook or **Resource 5** to identify foods that they eat regularly which are rich in proteins, carbohydrates, fats or vitamins and minerals. Discuss their lists and remind them of the idea that some nutrients (e.g. carbohydrates) are needed in much larger quantities than others (e.g. vitamins and minerals). Approximate amounts of the daily requirements of some nutrients are shown on the resource sheet. Explain that actual amounts will vary according to how old you are, how active you are, whether you are a boy or a girl and how big you are. Ask each student to design a menu for the day that would give them a balanced diet as well as being nice to eat.

If there is time at the end of the lesson, some students could read out their diets. Alternatively, students could exchange their work with their neighbour and read their diets.

3. Conducting research on local food issues

Encouraging students to ask questions and giving them choices about their work are both important when you are teaching them to be creative and to solve problems. By conducting their own research on a topic of their choice, they have ownership of the problem and will develop other skills alongside learning about science. The work they produce could even be of interest to future employers. They have freedom to choose an area of interest and to research it in their own time and in their own way. While this activity will take the students some time to complete, it does not take up much class time and it will give them an opportunity for independent learning. **Case study 3** shows what students can do by simply making use of friends and families and **Activity 3** also shows what else they could do if they have access to a library or computers. They will practise sorting through a range of information and presenting it in a poster or booklet to their colleagues. You could explain that this is an important way that scientists communicate their research to other scientists at international conferences.

Case study 3: Research using friends and family

Mr Saiti is worried that some of the pupils in his class do not get a good balanced diet. Many have family plots at home for growing food, but these do not always yield a good harvest. He decides to set his class a competition to research good techniques for growing crops on a small scale. They should base their research on talking to people they know and other people in the community. He wants them to use their scientific knowledge to explain the techniques that they hear about. He divides the class into groups of four students. He asks each group to display their findings in a poster and tells them that there will be a prize for the best plan. He puts the judging criteria (**Resource 6**) on the classroom wall so that the students can see what he will be looking for and plan their work accordingly. Hari's group are very enthusiastic. Hari goes down to the local market. He picks the stall with the nicest looking vegetables and chats to the owner about how he grows them. Sakina's aunt works in a local clinic. Sakina asks her about the sorts of illnesses that local people have and as a group they work out what sort of food would help improve local diets and reduce the likelihood of illness due to nutrient deficiencies.

Mr Saiti has already noticed a small plot of land that belongs to the school, but which is not being used. He has asked the headteacher if he could use this plot with his class to develop a small garden to grow vegetables and fruit. The headteacher has agreed to his request.

Activity 3: Organising a research project

Divide your class into groups of up to four students. Explain that you would like them to identify a local food issue to research. Give them time in class to decide on the issue they will research and to plan how they will carry out their research. Encourage them to talk to their family and other friends to identify a local issue or concern. If possible, they could also use a library or the internet. You could spend a short time with the whole class doing a brainstorming activity to generate ideas for suitable topics. **Resource 6** has some ideas to start the students thinking. Tell them they have 3 weeks to do the research and prepare a poster, a set of leaflets or a scrap book that will be displayed in the classroom. When they have done this allow them time in the lesson to go round the exhibition and to evaluate each others' work.

Resource 1: Problem solving and creativity

Teacher resource to support teaching approaches

Problem solving and creativity

Through being resourceful and engaging and providing variety, you will be able to motivate your students. If you are willing and able to solve problems and be creative, you will be able to help your students develop these skills. And it is not as difficult as it might seem!

Creativity

Creativity is about the ability to think. It is not just about remembering, but also applying, suggesting, extending, modelling, and offering alternatives. It is something that you can model for your students. Students need to be encouraged to think differently and come up with original ideas. They also need to feel confident in the reception they will get before they make such suggestions.

Some teachers will naturally be very creative, but some will not – and that is fine as long as you are resourceful and willing to try new ideas. A creative teacher, for example, will take the TESSA Secondary Science units and apply the strategies we suggest to different contexts. You could use news items from radio, television or newspapers and relate this to the science you are teaching. You can set open-ended tasks and allow students to make choices about how they present their work. You may take some risks in your teaching. Above all, you will create an atmosphere of excitement and enquiry with dramatic demonstrations, enthusiasm or amazing and unbelievable facts.

Strategies to promote creativity
Get students to: • write a story to illustrate a scientific principle • draw a picture to illustrate a scientific principle • make up a play • make a model • take part in a role play (e.g. be the particles in a solid, liquid or gas) • make up a poem or a rap • think up alternative explanations for something they see • write a letter or newspaper article or podcast.

Problem solving

Helping students to develop problem-solving skills is a frequently cited goal of science teachers. As with creativity, you can model these skills in your own classroom. For example, if you can't answer a student's question, you can come back next lesson with a solution and explain how you worked it out and why you found it hard. Being able to solve problems involves developing thinking skills. There are various strategies that you can adopt to help children develop these skills (Wellington and Ireson, 2008):

- **Encouraging student-generated questions.** The act of asking questions requires engagement and creative thought, two core cognitive strategies.

- **Being clear about 'purpose'.** Students should be encouraged to ask: what is this all about?' 'What does this relate to?' 'Why do you want us to do this?' – rather than embark on activities in an unthinking, recipe-following fashion.
- **Setting open-ended activities.** Teachers should set activities that can be tackled in a variety of ways so that children have to think about how they will tackle the problem.
- **Planning.** Teachers need to provide opportunities for children to plan their problem-solving strategy in a systematic way.
- **Paraphrasing.** It is well known that you really get to know and understand ideas when you try to teach them to someone else. Giving children opportunity to paraphrase an explanation will help them to understand difficult ideas and to be aware of their own learning.
- **Learning to learn (metacognition).** Teachers can encourage children to become more conscious of their learning by getting them to think about why they don't understand and what strategies helped them that might be useful in the future.

Reference

Wellington, J. and Ireson, G. (2008) *Science learning, Science teaching*. Abingdon: Routledge.

Resource 2: Kabwe’s story

Teacher resource for planning or adapting to use with pupils

Kabwe’s story

Kabwe, a 21-year-old man, is a newly appointed Basic School Diploma teacher. He was recently recruited from Kasama Teacher Training College to teach grades 8 and 9 at Katoma Basic School in Chinsali District of Zambia. In order to familiarise himself with this new school, Kabwe went to meet the local village headman, 75-year-old Chanda Bwalya. Kabwe wanted to shed some light on the history of the village and the development and future of the school.

Kabwe noticed that there were problems in the village. There were very few trees in the area, recent harvests had been poor and there were low levels of rainfall. Some of the children in his class did not come to school very often and several of them had protruding tummies, and small legs showing a lot of suffering and hunger.

Chanda Bwalya, the local village headman, praised the ancient days when they founded the village; there was plenty of water in the surrounding streams, and large number of large wild trees with fruits which engulfed the new village. They used to get large crop harvests from very small portions of land they had tilled. It was their custom to use the shifting cultivation system known as chitemene for farming, which involved growing maize or food in one field until it no longer produced enough food then shifting to another area. The trees had provided fruits but also firewood and charcoal. Now the area is a semi-desert. The plants are growing stunted, the yield is poor and there are very few trees left.

Chanda Bwalya blamed the crop failure, lack of wild fruits and the lack of water in most of the streams on misfortune which had befallen the village. Respect for the ancestors had reduced drastically and no yearly rituals for thanking them had been conducted for several years. Chanda also blamed the schools for the bad manners they were teaching the children such as stopping the villagers from cutting trees and planting maize for several years in one garden. The issue of planting new trees was not a village problem but God’s problem as he comes to replace the trees after some time. Chanda Bwalya hinted at the bad times they were going through and was hopeful that things would change for the better once certain solutions were introduced such as paying homage to the ancestors, respect of elders and many more.

Kabwe, the teacher, reminded the village headman that there were no new trees coming up to replace the ones that had been cut down and this was causing the area to become desert. He suggested they planted trees and changed to new methods of organic farming. The old man refused to agree with Kabwe reminding him that he was too young to understand how God and our ancestors replace the lost trees. He should first spend some time in this village and then he would experience the growth of new trees. Chanda Bwalya suggested that Kabwe was too young to understand how these problems had befallen his village and its school.

Kabwe, after listening to the old man for over 2 hours, became more tense in his mind and started contemplating how he would manage his new job in such an environment and what he could do to change the existing beliefs and norms to more modern approaches so that the pupils and the community could move forward and their health could improve.

The poor health of most of his pupils worried him and the newly created desert in an area which previously had large trees and the poor harvests the people were experiencing concerned him.
.

The next day, Kabwe returned to his classroom. Overnight he had fully reflected on the stories he had heard from old Chanda Bwalya. He was determined to help the village find a solution to their problems.

Notes on Kabwe's story

Below are some problems in the village that your students should be able to identify. See what ideas they think of themselves before you share these with them.

1. Poor crop harvests.
2. No wild fruit or other forest foods such as mangos which can supplement diet.
3. Poor nutrition of some pupils – affecting health and school attendance.
4. Low rainfall.
5. Greatly reduced water flow in local streams.
6. Soils lacking in nutrients and becoming dry and desert like.
7. Resistance to organic or different farming methods, e.g. the same crops grown on a plot of land every year; not using animal manure and collecting organic waste to make compost.
8. Loss of native forest trees.
9. Poor communication and mutual understanding between traditional villagers, such as the headman who feels that traditional ways and respect for ancestors is being lost, and younger people from outside the village with new ideas.

Here are some questions you could get your students to think about:

- Why was their village lacking wild fruits?
- Why was the area resembling a desert?
- What was causing the shortage of water in streams which used to be perennial?
- Why were the harvests from their parents' gardens yielding very little?
- What measures would they take to resolve these problems in their village?
- Who should they consult to assist with resolving these problems?
- What examples would they show to the local people that these problems could be resolved?

Resource 3: Background knowledge for Kabwe's story

Background information / subject knowledge for teacher

Solutions using biological knowledge

Knowledge and understanding of natural interactions between living organisms and their environment, including soil and water availability, can be applied to situations where human intervention has created problems. It can be used to develop solutions to help alleviate the problems.

Main areas of biology syllabus which relate to this story

1. Nutrient cycles such as the nitrogen cycle and carbon cycle.
2. Problems associated with human population growth and depletion of resources.
3. Soil fertility, resource management and improved farming practices.
4. Effects of human activity in causing deforestation, soil erosion, drought, flooding, loss of biodiversity (genetic material for future crop breeding and potential economic resources such as yet undiscovered medicines).
5. Components of a healthy diet.

Scientists and communication

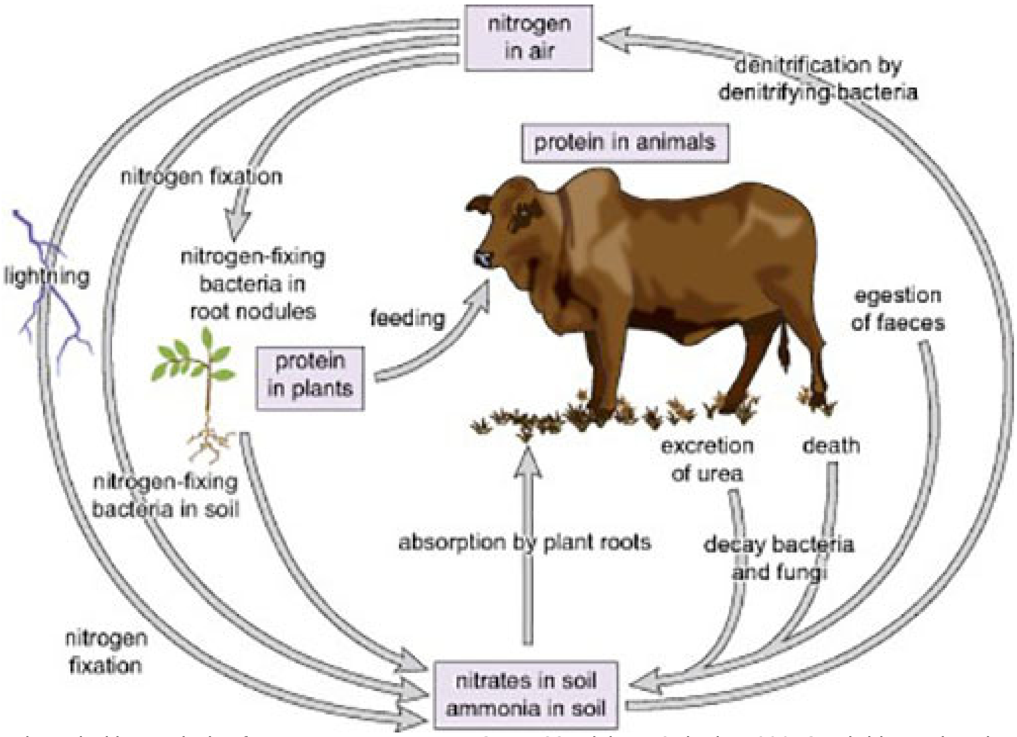
As well as doing and understanding science themselves, scientists must be able to explain scientific ideas to the general public and persuade them of the advantages of new techniques where appropriate. They need good communication skills. This includes listening to the views of others, analysing them critically and being prepared to learn from others. Some problems need to be solved by taking account of a balance of scientific, economic and cultural considerations.

In this story, the headman laments the lack of respect for ancestors. Biologists have a respect for the natural environment. It may be that common ground can be found by negotiation.

Listening is also important as the local knowledge of community members can be extremely valuable. This is internationally recognised as an important concept. Such knowledge should not be stolen nor its holders exploited.

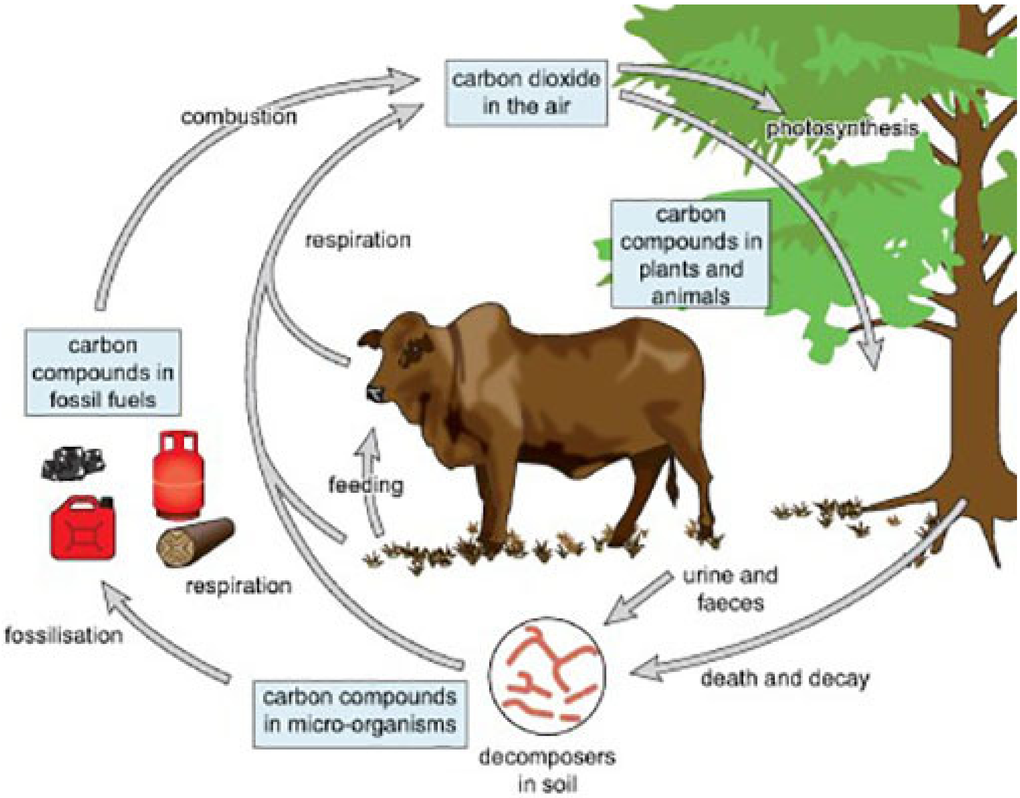
Poster 1 The nitrogen cycle and the carbon cycle

Harvesting crops reduces the carbon and nitrogen going back into the soil.



Adapted with permission from Jones, M. & Jones, G., p.188, Biology, 3rd edn, 1996, Cambridge University Press, Cambridge, UK.

Diagram 1 Nitrogen cycle



Adapted with permission from Jones, M. & Jones, G., p.188, Biology, 3rd edn, 1996, Cambridge University Press, Cambridge, UK.

Diagram 2 Carbon cycle

Methods of conserving and renewing soil fertility

Application of manure, compost or artificial fertilisers: Removing crops at harvest interrupts natural nutrient cycles and prevents nutrients from dead remains returning to the soil to replenish nutrients. To make good the losses, farmers can apply manure, compost or artificial fertilisers. Animal manure decays to give nutrient salts. It also supplies humus which improves the water holding capacity of soils.

Crop rotation: If crops are chosen carefully this can reduce the amounts of any one mineral which is removed from the soil. It also reduces the likelihood of harmful pests and parasites building up in the area and adversely affecting crop yields. A leguminous crop is often included in the rotation so nitrogen levels can be built up in the soil due by the action of the nitrogen-fixing bacteria in their root nodules.

Poster 2 Human population growth – depletion of resources

As the population grows, more food is needed. If it is not available, people suffer from malnutrition. Also, people need to make a living and they often do so by selling resources such as timber from rainforests.

Malnutrition
This is caused by not eating enough of all the necessary components of a healthy diet. The main components of a healthy diet are protein, carbohydrate, lipid, vitamins, minerals and water.

Why traditional practices that used to be successful now need to be modified
Traditional practice of 'slash and burn' agriculture did no long-term damage to forests when population densities were low. Given time, the 'bush fallow' between clearances provided a natural rotation system that allowed the forest and its soil time to recover. Human population expansion and competing land uses such as plantation agriculture (rubber, oil palm) and hydroelectric power schemes have reduced the fallow period.

In addition to subsistence farming systems, forests are being removed for fuel wood gathering. Also, they are now being removed at an increasing rate by commercial logging for tropical hardwood timber (mainly for rich countries), for wholesale burning and clearing for cattle ranching (beef at cheap prices).

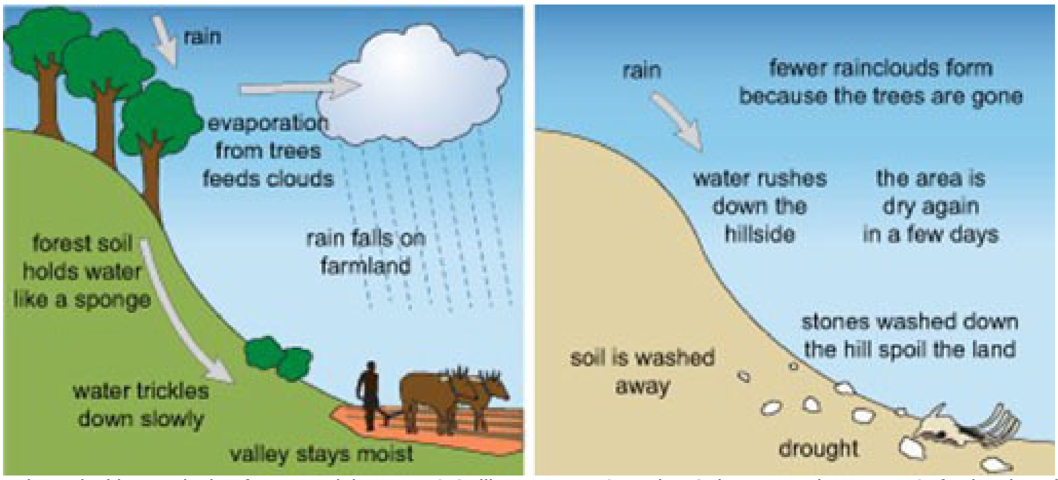
Poster 3 Soil fertility, resource management and improved farming practices

Organic practice
Organic practice focuses on maintaining a healthy and fertile soil using animal manure and compost rather than artificial fertilisers. This provides nutrients and also increases the water holding capacity of the soil. It also advocates using crop rotation. Where possible, rainwater should be collected. The need for watering can be reduced by improving the soil and growing appropriate plants. Native species should be grown where possible. Natural wildlife areas should be encouraged adjacent to crops so crop pests are controlled by natural predators.

Sustainable resource use
Where forests are cut down, for example as a timber resource, this should be done in a sustainable way. This means, with thought for future generations, i.e. as trees are cut down, new saplings should be planted.

Poster 4 The effects of human activity

Water and nutrient availability and soil erosion
Deforestation accelerates desertification by reducing rainfall. When the forest trees are cut down, the water cycle is disrupted. The reduction in transpiration (the evaporation of water vapour from the surface of the plants) results in fewer clouds and less rainfall in the vicinity. Surrounding forests are threatened by desiccation. As the land becomes hotter and drier, more of the soil is eroded.



Adapted with permission from Merrick, W., & O'Sullivan, J., p. 43, Action Science: Environment, Oxford University Press 1990, Oxford, UK.

Diagram 1 Effects of deforestation

Rainforest soils are poor in nutrients. In rainforests, virtually all the nutrients are in the organic matter of the forest canopy. Normally when dead organisms fall to the floor and are decomposed into nutrients, these nutrients are quickly reabsorbed into the living plants. If, however, the forest is felled and the trees removed, the soil nutrient source is removed too, so soils quickly become nutrient poor. The soil is of little use even for subsistence agriculture and soil erosion usually follows.

Forests are often on uplands and on watersheds. They catch and hold large amounts of rain and release the water slowly and reliably into rivers and streams. Deforestation of uplands disrupts regular water supplies and can result in much disastrous flooding of the plains below.

Trees help to stabilise soil. Deforestation results in soil erosion. This means food production is affected and can result in hunger and economic losses. Reservoirs and water supplies can silt up and harbours and estuaries must be continually dredged to keep them open.

Loss of biodiversity
Forests are extremely species rich. Their destruction will lead to innumerable extinctions of unknown and little known species, with consequent loss of genetic variety and potential resources.

Forests and climate change
Forests are an important carbon sink (together with plankton in the oceans). This is an important role within the carbon cycle. Removal of forests contributes to an increase in atmospheric carbon dioxide, which can lead to climate changes due to the greenhouse effect.

Poster 5 Components of a healthy diet

If there is not enough of the necessary types of food available, people will suffer from malnutrition. Malnutrition is caused by not eating enough of all the necessary components of a healthy diet. The main components of a healthy diet are protein, carbohydrate, fat, vitamins, minerals and water.

Sources of the main nutrients

Food	Rich source of	Moderate source of
Cereals	Starch, fibre	Protein, B vitamins, many minerals
Starchy roots and fruits (yams, maize, cassava, potatoes, rice)	Starch, fibre	Some minerals, vitamin C if fresh, vitamin A if yellow or orange
Beans and peas	Protein, starch, some minerals, fibre	B vitamins
Oilseeds	Fat, protein, fibre	B vitamins, some minerals
Fats and oils	Fat	Vitamin A if orange or red
Dark to medium-green leaves	Vitamins A and C, folate	Protein, minerals
Orange vegetables	Vitamins A and C	Fibre
Orange fruits	Vitamins A and C	Fibre
Citrus fruits	Vitamin C	Fibre
Milk	Fat, protein, calcium, vitamins	
Eggs	Protein, vitamins	Fat, minerals (not iron)
Meat	Protein, fat, iron	
Fish	Protein, iron	
Liver	Protein, iron, vitamins	

Resource 4: Differentiating work

Background information / subject knowledge for teacher

Differentiating work for students of varying abilities

As you know, each pupil has different abilities. There can also be a significant difference in age between the oldest and youngest pupil in the class. Some students will learn more effectively by reading a book, some by carrying out a practical activity and some by listening to and absorbing spoken instructions. Some will understand the work very easily, some will take more time. Some will work very quickly through any task you set, some will work slowly. It is impossible for you as a teacher to take all the differences into account all the time, but there are things that you can do to support individuals within a class.

If you have a class of 40 or more pupils this might sound like a daunting task. There are two important things that you need to do to be able to effectively cater for everyone in your class:

1. **Know your students.** You need to give them opportunities to work in groups and listen to their conversations; you need to mark their written work; you need to ask questions of individuals in class and you need to encourage them to ask you questions if they don't understand or just want to know more. When you know who understands easily, who finds science difficult, who likes to talk, who likes to write, who likes to draw and who likes doing experiments, you will be in a much better position to help individuals.
2. **Know your subject.** It is unrealistic to expect everyone to remember and understand everything that you do. Students who find science difficult will be overwhelmed if you try to tell them everything. You need to break each topic down into simple steps and make sure that everyone understands the most important ideas. You also need to know how to challenge students who have grasped the basic ideas.

You can cater for the range of abilities within your group in two main ways:

Differentiating by outcome

This involves setting some questions that get progressively more difficult. Everyone gets as far as they can. Alternatively, you can set open-ended tasks in which students demonstrate what they can do. This also enables you to give them a choice about how they present their work, which can be very motivating. You may find that the degree of support that you need to provide to individuals, pairs or small groups within the class varies significantly.

Differentiating by task

For this, you set different students, or groups of students, different tasks. For example, in a practical session some pupils could have instructions provided for them in written form and some could have them in diagram form and some could have a combination of both.

You could provide a set of questions that cover the basic ideas that you judge that everyone needs to understand and a set that are more challenging. The students who you expect to get a grade A could be given the more challenging ones.

Learning style

There is a lot of research that suggests that different students prefer to learn in different ways. The three learning styles that are more commonly referred to are visual, audio and kinesthetic, i.e. some students prefer diagrams and pictures, some learn best by listening and some prefer to be able to do things.

As a teacher you cannot be expected to cater for all the students all the time, but a good teacher will make sure that their lessons contain activities that cover all three learning styles.

There is a tendency to expect students to do a lot of listening. You should make sure that your students also get to do experiments or activities that involve moving around the room and talking about science. Encourage them to use mind maps and diagrams or pictures to summarise key ideas, rather than simply copying notes off the board.

Resource 5: Data on food and energy

Teacher resource for planning or adapting to use with pupils

Food

A healthy diet requires adequate amounts of protein, carbohydrate, fat, vitamins, minerals and water.

A rough guide to daily requirements is as follows:

- protein 50 g
- carbohydrate 300 g
- fat 65 g
- fibre 30 g
- vitamin A 730 μg
- vitamin C 60 mg
- iron 11 mg (males), 15 mg (females)
- calcium 1300 mg.

Note the different units for different nutrients:

1 mg = 1/1000 g 1 μg = 1/1000 mg.

Sources of the main nutrients

Food	Rich source of	Moderate source of
Cereals	Starch, fibre	Protein, B vitamins, many minerals
Starchy roots and fruits (yams, maize, cassava, potatoes, rice)	Starch, fibre	Some minerals, vitamin C if fresh, vitamin A if yellow or orange
Beans and peas	Protein, starch, some minerals, fibre	B vitamins
Oilseeds	Fat, protein, fibre	B vitamins, some minerals
Fats and oils	Fat	Vitamin A if orange or red
Dark to medium-green leaves	Vitamins A and C, folate	Protein, minerals
Orange vegetables	Vitamins A and C	Fibre
Orange fruits	Vitamins A and C	Fibre
Citrus fruits	Vitamin C	Fibre
Milk	Fat, protein, calcium, vitamins	
Eggs	Protein, vitamins	Fat, minerals (not iron)
Meat	Protein, fat, iron	
Fish	Protein, iron	
Liver	Protein, iron, vitamins	

Sources of vitamins

Vitamin	Good sources
Vitamin A	Liver, fish liver oils, egg yolk, milk and dairy products, green leafy vegetables (especially kale, amaranth, sweet potato, cowpea and cassava leaves), yellow and orange-coloured fruits and vegetables (carrots, pumpkin, mango, papaya, oranges), orange-coloured sweet potato, palm oil
Vitamin D	Cod-liver oil, oily fish, liver, egg yolk
Vitamin E	Vegetable oils (such as maize, soybean and sunflower oils), nuts, soybeans, cereals, egg yolk
Vitamin K	Green leafy vegetables, vegetable oils, egg yolk, beef, mutton, poultry
Thiamine (vitamin B_1)	Millets, sorghum, wheat, maize, dried beans, rice, liver, kidney, beet, nuts
Riboflavin (vitamin B_2)	Green leafy vegetables, liver, kidney, milk, cheese, eggs, whole grains
Niacin (nicotinic acid and nicotinamide)	Lean meat, poultry, fish, groundnuts, dried beans, wheat, yam, potato
Pantothenic acid	Kidney, fish, egg yolk, most vegetables, most cereals
Pyridoxine (vitamin B_6)	Meat, poultry, fish, egg yolk, whole grains, banana, potato, dried beans, lentils, chickpeas
Biotin (vitamin H)	Groundnuts, dried beans, egg yolk, mushrooms, banana, grapefruit, watermelon
Folic acid	Green leafy vegetables (losses from cooking can be high), fresh fruits (especially orange juice), dried beans, peas, nuts, egg yolk, mushrooms, banana, liver
Vitamin B_{12} (cyanocobalamin)	Liver, kidney, chicken, beef, fish, eggs, milk, cheese

Extension activities: food and energy

We need energy to stay alive and carry out our daily activities. This energy comes from the food we eat. Energy is measured in units called **joules (J)**. One joule is quite a small amount of energy, so we usually use **kilojoules (kJ**) to measure our energy requirements.

- 1 kilojoule = 1000 joules.

Teenagers should eat enough food to provide them with between 10 000 and 15 000 kJ each day. The exact amount required will vary according to size (mass), age, sex (in general boys need more than girls) and activity.

On average, a teenage girl needs 11 000 kJ of energy each day.

On average, a teenage boy needs 13 000 kJ of energy each day.

Task 1

Plan a diet for a day for a teenage boy or girl. The food you select and the amounts of each food should be enough to meet the energy requirements of an average teenager as given above. Do not forget to include snacks as well as main meals.

Use the information in the table below to help you. You will need to estimate how many grams of each food you will require before you calculate the energy it provides.

Energy content of some common foods

Food	Energy content in kJ per 100g
Milk	272
Eggs	662
Chicken	771
White fish	289
Oily fish	796
Haricot beans	1073
Broad beans	289
Lentils	1236
Green peppers	88
Potato	364
Cassava	667

Food	Energy content in kJ per 100g
Rice	1504
Banana	318
Melon	96
Orange	147
Spinach	88
Biscuits (sweet, rich)	2078
Bread (brown)	993
Bread (white)	1060
Pasta	1525
Maize meal	1350
Yams	462

You can record your diet plan in a table like the one below.

Energy content of a sample diet for a teenager for one day

Meal	Food item	Amount of this food in g	Energy content of this food in kJ per 100g	Total energy provided by this food item in your diet

- Calculate the **overall total energy in kJ** that your diet will provide.
- How does this compare with the average requirements for a teenager of your sex?

Diet, energy and activity

Your energy requirements will vary according to your activities. The table below shows the energy requirements for different activities.

Energy requirements for different activities

Activity	Energy required for each minute by an average teenager in kJ
Sleeping	4
Watching TV	5
Eating	6
Washing clothes	10
Gentle walking	12

Activity	Energy required for each minute by an average teenager in kJ
Sewing	12
Digging the garden	24
Swimming	30
Playing football	36
Sprinting	60

Task 2

Plan a day where you do various activities for a certain length of time.

A day lasts 24 hours or 1440 minutes.

Activities (and their durations) you might choose could be sleeping, 480 minutes; eating, 50 minutes; swimming, 70 minutes and so on.

Work out how many kilojoules of energy you would need for each activity.

You could record your answer in a table like the one below.

Activities in a day and energy required to perform them

Activity	Minutes	Energy required per minute for this activity in kJ	Total energy required for the duration of this activity

- Calculate the **overall total energy in kJ** that your activity plan would require.
- How does this compare with the amount of energy your diet in Task 1 would provide?

Resource 6: Suggestions for conducting and assessing research

Background information / subject knowledge for teacher

Suggestions for research

- Nutritional values of local foods not mentioned in national textbook.
- The organic movement.
- Mother's milk or powdered milk?
- Health problems associated with obesity.
- How our diet has changed. (Encourage students to interview grandparents – if possible use a recording device.)
- Can we believe adverts about food?
- What are the main causes of malnutrition in our country?
- Assess the nutritional value of the meals served in the dining hall of students in a boarding house of a senior high school in your locality.
- Determine the calorific value of the meals served to pupils under the school feeding programme of the government.

Criteria to evaluate the projects

The criteria used by Mr Saiti in (Case study 3) to judge the competition he set his class to research good techniques for growing crops on a small scale were as follows:

1. Have the pupils taken note of the existing conditions in the plot?
2. Have they suggested what tests, if any, they will do to find out more about how the plot is suited to crop growing?
3. Have they suggested what preparatory work must be done before planting, including what measures they have taken to prevent stray animals from invading the plot?
4. Have they researched what crops are grown successfully in the locality by other people?
5. Have they tried to choose a mix of crops that will provide all the requirements of a healthy diet?
6. What special conditions do these crops need and how could they meet these conditions?
7. What plans have been made for looking after the crops?
8. How will they organise a water supply for the plot?
9. How will they prepare for and deal with potential pests or disease?
10. When would planting take place?
11. When would harvesting take place?
12. What do they suggest is done with the harvest?
13. Have they thought ahead about what would be planted in future years (crop rotation) and how they can recycle nutrients (composting)?
14. What plans do they have for making other people aware of the scheme?

Criteria for evaluating research projects

These criteria relate to Activity 3 and the score card below.

1. Has the group stated the aims of their research clearly?
2. Has the group collected sufficient evidence from a range of reliable resources?
3. What scientific knowledge and understanding from their biology course has the group used in their research?
4. How clearly have they explained the results of their research findings?
5. To what extent have they used diagrams in an imaginative and creative way to explain their findings?
6. Do you think they have covered the main issues in their chosen area of research? Are there any additional questions you think they should have considered?
7. Is the project attractively presented? Is there an appropriate amount of text – not too much and not too little? Does the layout make you want to read it?
8. Have they suggested areas in which their research could be continued if they had more time to develop it?
9. Is there evidence that all members of the group have made an appropriate contribution to the work, using their particular skills?

For each poster, evaluators should give a score for how it was rated on each criterion.

Scores can be between 1 and 5:

5	Excellent
4	Very Good
3	Good
2	Needs more attention
1	Needs a lot more attention.

Score card

POSTER NUMBER	**1**	**2**	**3**	**4**	**5**
QUESTION SCORE					
Question 1					
Question 2					
Question 3					
Question 4					
Question 5					
Question 6					
Question 7					
Question 8					
Question 9					
TOTAL SCORE					

Return to Science (secondary) page

Section 5: Cells

Theme: Dealing with challenging ideas in science

Learning outcomes

By the end of this section, you will have:

- used pair discussion and probing questions to review and develop students' understanding of the basic structure of plant and animal cells;
- used mathematical activities that help students gain an idea of the relative size of cells;
- helped students make and evaluate their own models of cells.

Introduction

Your students will have been taught about cells in primary school. However, they are likely to have a number of misconceptions about what cells are really like. Developing an understanding of the size of cells is difficult. The fact that cells can only be seen with the aid of a microscope adds to this difficulty. Research has shown that some students confuse ideas about cells and molecules, including their relative sizes. Although three-dimensional diagrams of cells may be shown in textbooks, photographs of cells as seen under the microscope are always two dimensional. It is difficult for students to imagine the 3D structure. Other common incorrect ideas that students may hold about cells include thinking that plant cells are surrounded by cell walls *instead of* cell membranes, rather than *by both* a membrane and a wall.

1. Focus on language to support understanding

Researchers have established a clear link between language and learning. When students discuss ideas with peers, they have time to draw on their memory of what they have done before, share ideas with their partner and clarify their thoughts by having to explain them to others. It also helps them to get used to the scientific words, which might not be familiar to them. You get the chance to listen to what they are saying and look at what they are writing, so that you are aware of their misconceptions when you plan your questions at the end. You are far more likely to address their misconceptions in this way. Too often when we use questions in a whole class discussion, we assume that because one student can give us a correct answer, the class as a whole understands the topic well.

Activity 1 will take more time than simply explaining cell structure to the whole class and asking them to copy labelled diagrams and notes. However, it will help the students to understand.

Case study 1: Creating a word wall

Mrs Keraro worked in a secondary school in Moshi, Tanzania. She was concerned that her 13-year-old students found scientific words difficult to pronounce and remember. She created a 'word wall' in the classroom. Every time they started a new topic she wrote the key words on card from an old cereal packet and stuck them on the wall. Whenever she had 5 or 10 minutes to spare in a lesson, she would play a game with her class. One person pointed to a word and someone else had to say it and explain the meaning. Alternatively, she divided the class into teams. She would say the meaning and one person from each team had to run to the wall and point to the word. She encouraged her students to make up different games. At the end of the year, their understanding of scientific words had improved a great deal.

She did this with the cells topic; she put up the technical words like 'chloroplast' and 'membrane', but also the easy words like 'cell' and 'cell wall'. This is because she thought her students might think they knew what a 'cell' was – a small room where a prisoner is kept! Lots of scientific words have different meanings in real life and she knew that this often confused her students. She also put up two large photographs of cells as seen using a light microscope. She asked the students to look carefully at the pictures and to talk about them in their pairs. During their discussions, she asked them to write down three interesting observations about the object in each photo. She also asked them to think of two questions which they would like to ask about each of these objects.

Activity 1: Working in pairs to discuss cells

Before the lesson, draw diagrams of generalised animal and plant cells on the board, without labels. Ask each student to copy the diagrams. Also, on the board write the names of the main structures (see **Resource 1**). Tell pupils to work in pairs or threes to label the diagrams and annotate them with the functions of each part. No one is allowed to write in the label or the function until they all agree. Talking about the answers will help them to learn. While they are working, move round the room. Visit the back of the room first. When you discuss the labels, your initial questions will mainly focus on recall, but try to follow these up with a more demanding question. You could check their understanding at the start of the next lesson by using the true/false exercise (**Resource 2**). Again, let your students work in pairs and discuss the answers.

2. How big are cells?

It is very difficult for us to get a real idea of very small and very large sizes. So, when we are thinking about things like molecules, cells or the solar system it can be helpful to compare their size with things we are familiar with. In **Case study 2**, the teacher was fortunate enough to have a good, working microscope and was able to give concrete experience of one of the measurements on the worksheet. When the students do the calculations in **Activity 2** they will consider the dimensions of a cell in a number of ways. The activity will help them to develop an understanding of cells, as the building blocks of living things, rather than as diagrams in a book. It will also give them practice of numeracy skills in science and give you an understanding of their ability in maths. This may affect your planning when teaching other science topics with a mathematical content.

Case study 2: Looking at onion cells

Mr Baguma had one microscope to use with his class. He also had 40 glass microscope slides. He did not have cover slips for the slides, but he used a second slide instead of a cover slip when preparing slides with his class. He divided the class into groups of four. Mr Baguma showed the microscope to the whole class and pointed out the main parts and what they do. He demonstrated how to prepare a slide of onion cells to view using the microscope and explained how to use a ruler with the microscope to estimate the size of the cells (**Resource 3**). He then asked each group to make a slide of onion cells. The groups took it in turns to come up to the front bench to look at their slide using the microscope. While they were waiting to use the microscope, Mr Baguma set some questions and calculations for the class to work on to help them appreciate just how small cells really are (**Resource 4**). He realised that some of the students were finding the questions difficult, which was a problem as he needed to help with the microscope. So he encouraged the students to help each other. The rule was that they could only write down the answer if they understood where it had come from. Jophus is very good at maths and really enjoyed helping his friends. After each pair had measured their onion cells, they were allowed to write the measurements in a table Mr Baguma had drawn on the board. At the end of the lesson, they could see that there is variation in cell size, but that the variation falls within certain limits.

Activity 2:Thinking about the size of cells

Remind students that you can only see cells with a microscope. Discuss why this is so. Probe their understanding of magnification and use analogies such as buildings made of stones or bricks. If you are far away you can only see the building, but as you get closer you see the bricks or stones. Compare cells to atoms and molecules which are much too small even to see under a normal microscope. Ask pupils to guess how big cells really are. Explain that most cells are between 0.01 mm and 0.1 mm in size. Do they know anything else that is so small? Can they imagine this size? Ask them to carry out all or some of the calculations in **Resource 4** . If there are students who find maths difficult, you could ask them to work in pairs. When you check the answers, discuss the extent to which these exercises helped their understanding and ask them to write their own questions.

3. Building Models of cells

One way of helping your students to visualise things like cells (or viruses or molecules) is to let them build models. **Resource 6** explains some of the advantages of using models in science. A resourceful science teacher will collect materials such as cardboard packets, plastic, packaging materials, wood and clay so that when they wish to build models, they have materials the students can use. You could also ask your students to collect materials and keep them in a cardboard box in your classroom. When students see cells in diagrams or on microscope slides, it is quite difficult for them to imagine the cells in 3D. You should encourage them to think about materials that will best represent their ideas of what a cell is like. Getting them to plan and deliver a presentation about their model means that they will have to clarify their own thoughts and explain them to others. Our understanding of abstract concepts is closely linked to our ability to use language to order our thoughts about them. While there are advantages in asking students to present to the whole class, this can take a lot of time and many of the benefits are just as great if they do the presentation to a partner.

Case study 3: Making and assessing models

Mrs Muthui had been teaching for 2 years. When she was at college her tutor had encouraged her to use models with her students. Last year her students made models of cells, but Mrs Muthui did not think it had worked very well. The students did not really understand what she was looking for. So this year, she did it differently. She showed her students some of the ones that she had saved from last year. She asked them which one they thought was the best and to explain why. Together, they made a list of marking criteria for the models. She then gave the class two weeks to make a model, working in groups of two or three, and was delighted to find them in the classroom before and after school, working on their ideas. She organised a display and asked her students to mark each others' models. She invited the head of department and the headteacher to see the display. Everyone was talking about it and some of the other teachers came to see as well. Mrs Muthui was delighted. The models were much more creative and imaginative than last year and she realised that sharing the marking criteria with the students had helped them to understand what was expected of them. She began to do this more often and gradually found that the students took more responsibility for their own learning.

You can see the criteria in **Resource 5** – but don't just use those, make up some of your own.

Activity 3: Making and presenting models

In teaching about cells, you will have introduced your students to cells that are adapted to a particular function, and you will have encouraged them to draw diagrams of the cells in their notebooks. Ask them to make a 3D model of one of the cells they have learned about. Give them materials such as cardboard, water, clay, wool, plastic drinks bottles, plastic bags or yoghurt pots, but also encourage them to use any other available materials.

When they have made their models, ask them to prepare a spoken presentation on the model. They should explain the structure of their cell and how it is adapted to its function. Encourage them to point out any aspects of the real cell which they could not show accurately on their model. They should all get the chance to work in pairs, giving their presentation to their partner. If you have time, you could choose the best models and ask those students to make a presentation to the whole class.

Resource 1: Background information on cells

Background information/subject knowledge for teacher

Diagrams of a plant and an animal cell

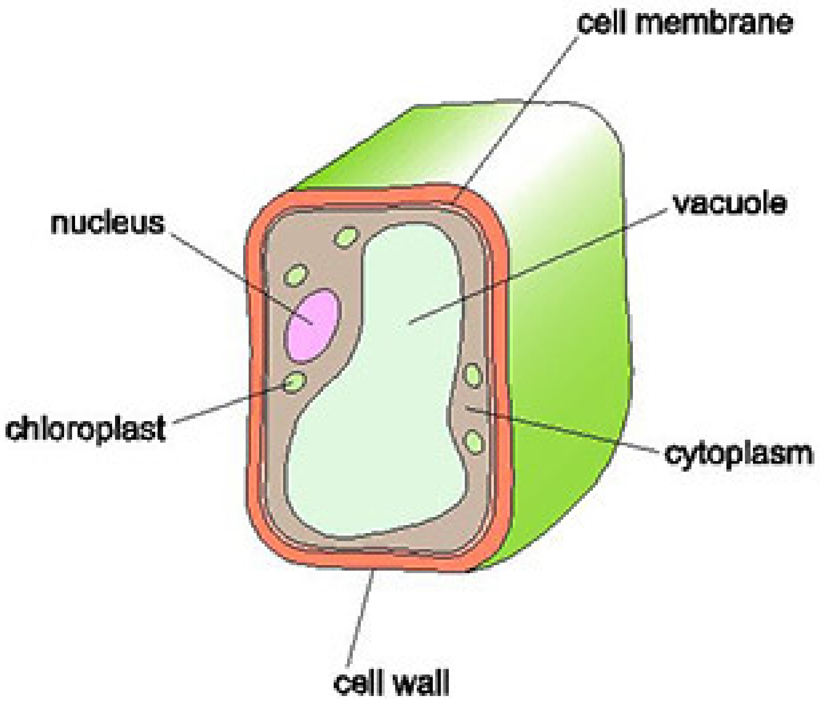


Diagram 1 : Typical plant cell in 3D, cut through to see inside.

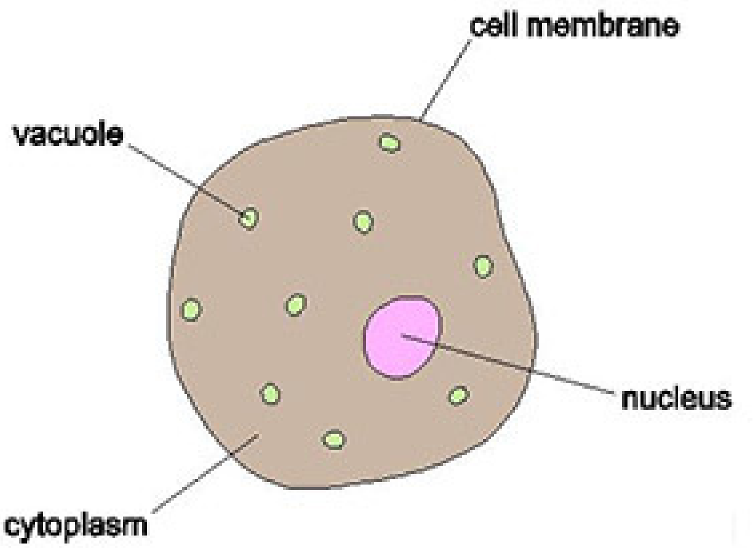


Diagram 2 : Typical animal cell, shown in section.

Teachers' resources

Names of cell structures for students to label diagrams of plant and animal cells:

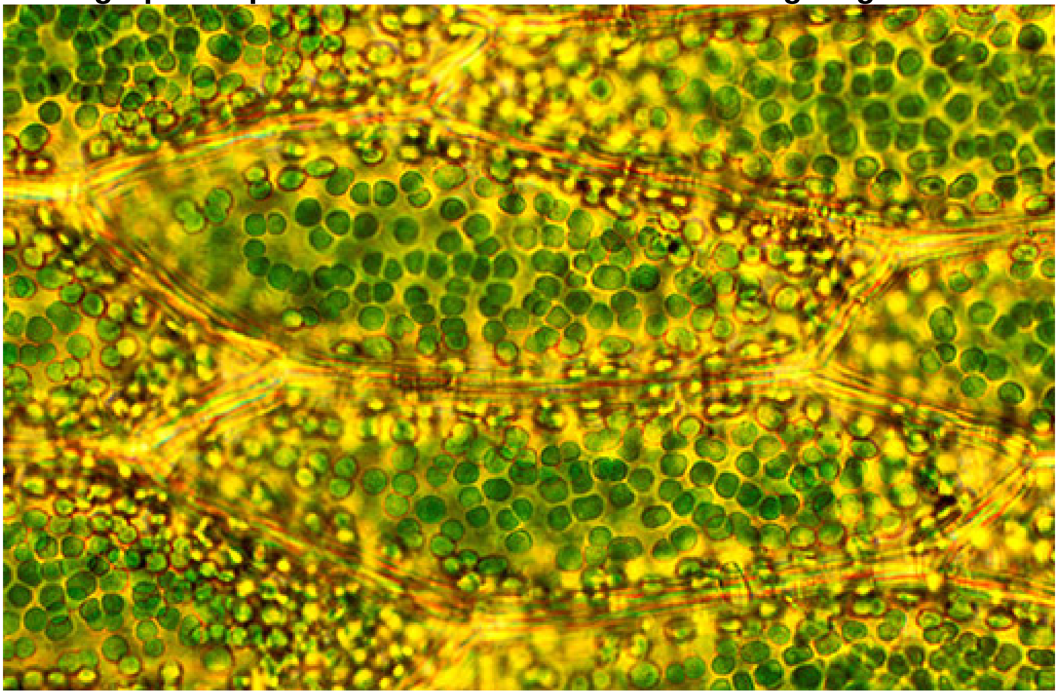
A. Central cell vacuole
B. Cell membrane
C. Nucleus
D. Cytoplasm
E. Chloroplast
F. Vacuole (small)
G. Cellulose cell wall

Information about cell structures for students to use as annotations on diagrams of plant and animal cells:

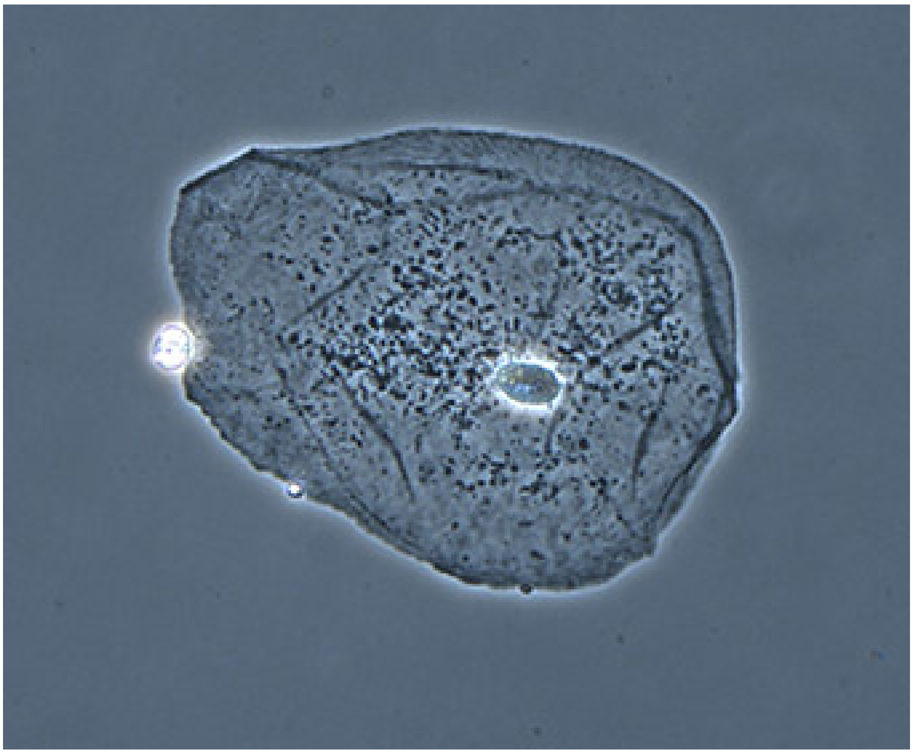
(A structure may have more than one annotation. Some annotations apply to both plant and animal cells.)

1. The outer layer of this cell is firm and rigid. It is made of cellulose. It gives the cell a definite shape.
2. The outer layer of this cell is not very rigid. It causes the shape of the cell to be flexible.
3. This is a large central area in the middle of the cell. It is filled with liquid. This helps to make the cell firm and gives support to the whole plant.
4. This structure controls what goes into and what comes out of the cell.
5. This structure controls what the cell is like and how it works.
6. This is a jelly like fluid containing many granules. Activities such as releasing energy and making proteins happen here.
7. These structures are used to make food by photosynthesis.
8. These are small vacuoles found in cells. They may contain food particles, chemicals made by the cell or germs that are being destroyed by the cell.

Photographs of plant and animal cells as seen using a light microscope:



Cells from a moss leaf.



Cells from inside the human cheek.

Resource 2: True/false exercise on cells

Teacher resource for planning or adapting to use with pupils

Plant and animal cells: true–false exercise

The following statements are about cells.

Read each statement and then in your group decide, for each statement, whether it is true (T) or false (F). If you are not sure put '?'.

Write the letter or symbol to show your decision in the middle column. Use the last column to explain your reasons.

	Statement	**True, false or unsure**	**Comment – reasons for your choice**
1	All cells have a nucleus.		
2	There is a cell membrane around all cells.		
3	All cells have a cell wall.		
4	Chromosomes are found in the cytoplasm.		
5	The cell membrane controls what the cell will look like and how it behaves.		
6	The nucleus controls what passes into and out of a cell.		
7	A nucleus is smaller than a chloroplast.		
8	A chloroplast is larger than a mitochondrion.		
9	All cells have a central cell vacuole filled with fluid.		
10	The cell membrane is made of cellulose.		
11	The nucleus is always found in the middle of a cell.		
12	A nucleus is smaller than a molecule.		
13	Some cells in your body are one metre long.		
14	If you looked through a magnifying glass at a red blood cell, it would look like the dot at the end of this sentence.		
15	A fully grown human is made of about one hundred million, million cells.		
16	Fifty typical cells lying side by side would measure about 1 mm.		
17	Cells are black and white. There is no colour in a cell.		
18	If you could shrink and stand in a cell, everything would be silent and still.		

Teachers' notes: statements 1–9

Statement	True, false or unsure	Notes for teachers
All cells have a nucleus.	True, with some qualifications. See notes.	All plant and animal cells have a nucleus. In some cells, the nucleus may have disintegrated by the time the cell reaches maturity. Red blood cells have a nucleus when they are developing. However, when they are mature and doing their job of carrying oxygen round the body, the nucleus has broken down. The whole cell is full of the oxygen-carrying pigment called haemoglobin. Bacterial cells are usually described as having a nuclear area, rather than a true nucleus, because there is not a nuclear membrane round the nuclear area.
There is a cell membrane around all cells.	True	
All cells have a cell wall.	False	Plant cells are surrounded by a cell membrane and outside this is a fairly rigid cell wall. The cell wall gives the plant cell a more definite shape than an animal cell. Animal cells do not have a cell wall. They are surrounded by a cell membrane only. A cell membrane is much more flexible that a cell wall.
Chromosomes are found in the cytoplasm.	False	Chromosomes are found in the nucleus.
The cell membrane controls what the cell will look like and how it behaves.	False	The nucleus controls what the cell looks like and how it behaves.
The nucleus controls what passes into and out of a cell.	False	The cell membrane controls what passes into and out of a cell.
A nucleus is smaller than a chloroplast.	False	A nucleus is about three times as big as a chloroplast.
A chloroplast is larger than a mitochondrion.	True	A chloroplast is three or four times larger than a mitochondrion.
All cells have a central cell vacuole filled with fluid.	False	Plant cells have a central cell vacuole filled with fluid, called cell sap. Animal cells do not. Animal cells may contain one or several small vacuoles.

Teachers' notes: statements 10–18

10	The cell membrane is made of cellulose.	False	Plant ***cell walls*** are made of cellulose. Cell membranes of both plant and animal cells are made of protein and lipid.
11	The nucleus is always found in the middle of a cell.	False	The nucleus may be found in the middle or around the edge of a cell.
12	A nucleus is smaller than a molecule.	False	A nucleus is much larger than a molecule. The nucleus contains chromosomes – 46 in human cells. Each chromosome is made of a DNA molecule.
13	Some cells in your body are as long as metre.	True	Nerve cells are made up of a compact cell body with long thread like fibres extending out from the cell body. Some of these fibres, called axons, may be up to one metre long. Nerve messages are carried along these fibres.
14	If you looked through a magnifying glass at a red blood cell, it would look like the dot at the end of this sentence.	True	
15	A fully grown human is made of about one hundred million million cells.	True	
16	Fifty typical cells lying side by side would measure about 1 mm.	True	
17	Cells are black and white. There is no colour in a cell.	False	Chloroplasts are found in most plant cells. Chloroplasts contain the green pigment chlorophyll. Cells in flower petals will contain coloured pigments either in special structures like chloroplasts in the cytoplasm or dissolved in the cell sap. Animal cells, e.g. in the skin and eye of human will also contain coloured pigments.
18	If you could shrink and stand in a cell, everything would be silent and still.	False	Everything would certainly not be still. Cytoplasm is continually moving around. Molecules would be moving in and out of cells. In a muscle cell you might find yourself squeezed and released from time to time. The swishing of the streaming cytoplasm is likely to set up vibrations. Sound is vibration. If you could manage to shrink to fit in a cell your ears could probably manage to detect these vibrations as sounds!

Resource 3: Working with onion cells

Teacher resource for planning or adapting to use with pupils

Preparing a slide of an onion cell and measuring a cell

You will need:

Microscope

Scissors

Microscope slide

Dropper pipette

Cover slip

Clear plastic ruler

Dilute iodine solution.

Preparing the onion slide

What to do:

1. Slice an onion in two, lengthwise.
2. Remove one of the thick leaf-like structures from inside.
3. Pull away a piece of the thin papery lining of its inner surface.
4. Using scissors, cut a small square of this lining, about 5 mm x 5 mm.
5. Place this square on the centre of a slide.
6. Add a drop of dilute iodine solution – make sure the solution spreads below as well as above the square of onion skin. The iodine acts as a stain to make the structures in the cell easier to see.
7. Carefully lower a cover slip over the onion skin. Try to avoid trapping air bubbles.
8. Place the slide on the microscope stage. Examine first using the low power. Focus carefully.
9. Choose an area of the slide where the cells can be clearly seen. Switch to high power and refocus.
10. Look for the structures shown in the photographs in **Resource 1**.

Measuring the onion cell

What to do:

1. Place the ruler on the microscope stage under the low power objective lens.
2. Move the ruler so the edge with the scale can be focused in the centre of the field of view of the microscope, as in Diagram 1 below.

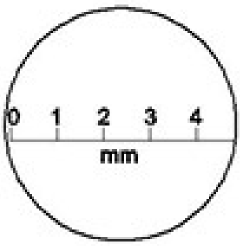


Diagram 1: The field of view of a microscope.

3. Use the scale to measure the field of view of your microscope.
4. The diameter of the field of view in Diagram 1 is approximately 5 mm.
5. You can use the measurement of the field of view in your microscope to estimate the size of objects viewed with the same objective lens.
6. The cell viewed in Diagram 2 would be about 2 mm long if viewed with the microscope with the field of view shown above.

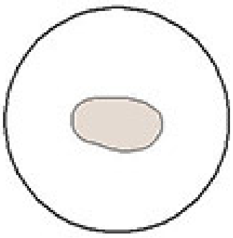


Diagram 2: Cell.

7. Estimate the length and width of your onion cell using this method.

Using a microscope

The main parts of a light microscope are shown below

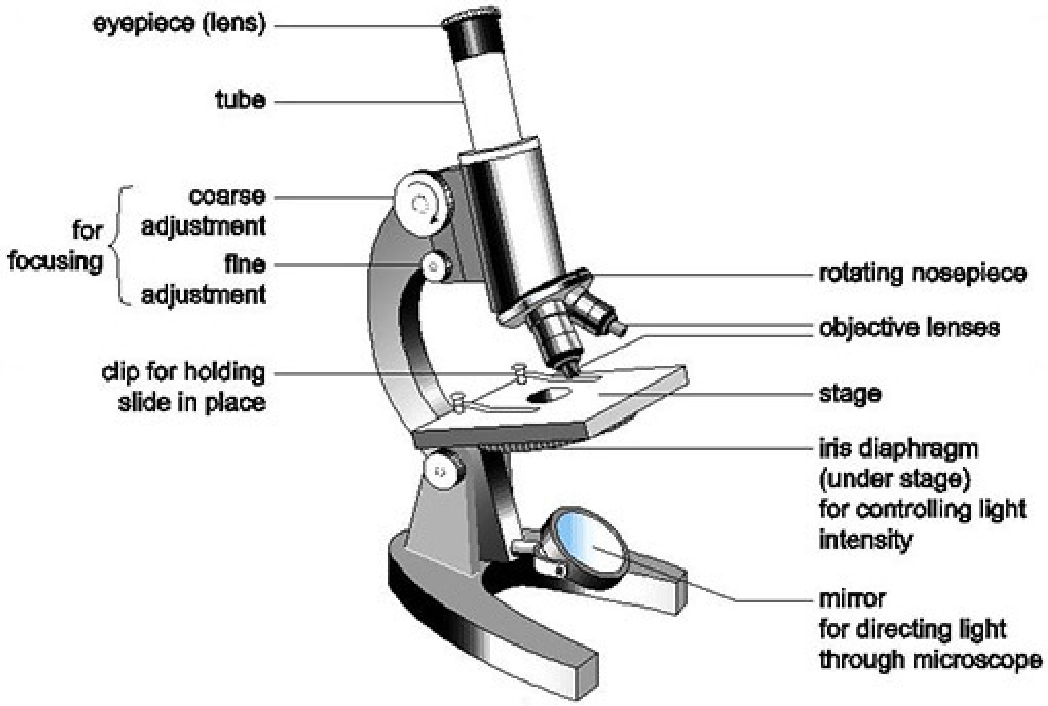


Diagram 3: Main parts of a light microscope.

Resource 4: Magnification exercise

Teacher resource for planning or adapting to use with pupils

Magnification exercise

1

One of the plant cells in the photograph really measures about 0.01 mm x 0.07 mm. Draw it in your book so its shape and proportions are nearly the same as in the picture.

Calculate magnification of the cell in this way:

Length of cell in drawing ÷ width of real cell = X ______

Mean magnification = X _________

Add this magnification to your drawing.

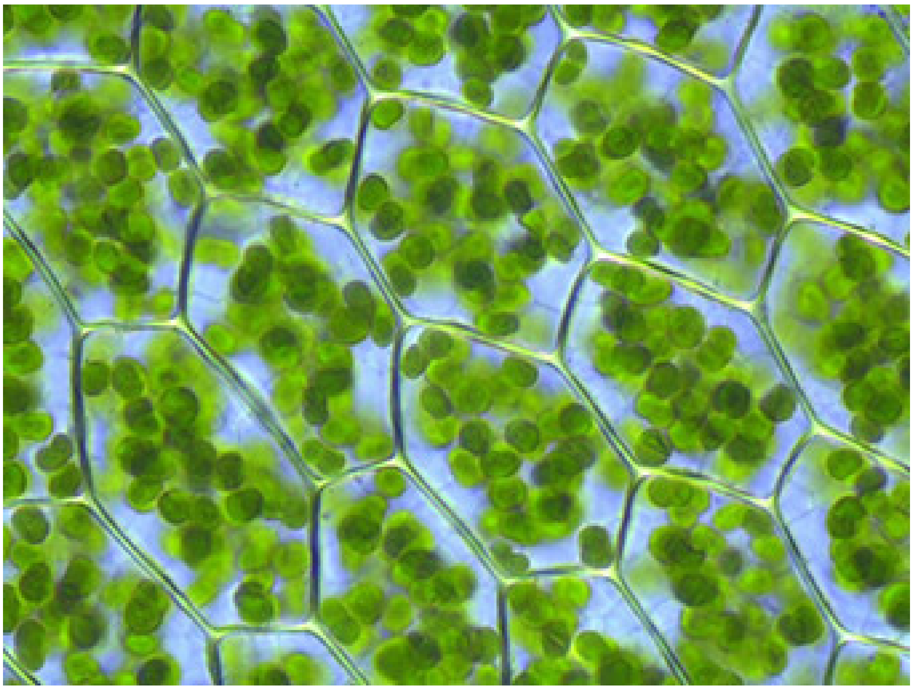


Photo from: http://commons.wikimedia.org/wiki/File:Plagiomnium_affine_laminazellen.jpeg (Accessed 2008)

2

Draw an animal cell that is nearly round in shape.

Measure the diameter of your drawing.

Assume this cell is really 0.02 mm in diameter.

Calculate the magnification and show it on your drawing.

3

Draw a line, 10 mm long.

How many of the animal cells could fit on this line side to side?

How many of the plant cells could fit lengthwise on this line side to side?

4

A person's stride length is about 1 metre.

If you were magnified by the same amount as your drawing of an animal cell, how far could you go in one stride?

5

Measure the length of a small animal such as an ant.

If its skin cells are 0.02 mm long. How many are there along the length of the animal?

6

Write your own question that helps you to understand the size of a cell.

Why does it help you to get a better understanding of this?

See if your neighbour or the rest of the class can work out the answer.

Resource 5: Assessing models

Teacher resource for planning or adapting to use with pupils

Criteria for assessing models of cells

1. Is the model clearly labelled?

   It should be obvious what all the parts are and they should be labelled.

2. Does it include all the relevant parts?

   All the key parts should be present.

3. Are the parts in the right proportion in terms of size?

   For example, if a tennis ball is used for the nucleus, the chloroplasts could be marbles.

4. Does the model reflect the nature of the cell? Have appropriate materials been used to represent the parts?

   For example, is the cell wall made of a rigid material? Is the cytoplasm squashy?

5. Does the model reflect the 3D aspects of cells?

   Children find this aspect of cells difficult to imagine and one of the main reasons for making a model is to show the 3D nature of the cell.

Resource 6: Using models in science

Teacher resource to support teaching approaches

Using models in science

Using models or analogies is a very powerful way of helping children to understand scientific ideas. Used properly, models can also help to develop critical thinking. You can do this by helping children to evaluate the strengths and weaknesses of a model.

Some general principles to think about when planning lessons with models are:

- introduce the model early in the teaching of the topic, then use the model consistently until it is replaced by a more sophisticated one
- ensure students make links between the model and the real situation
- ensure students recognise the differences between the model and what it is illustrating
- encourage students to apply their understanding to explain new ideas
- encourage students to identify strengths and weaknesses in any model
- increase the sophistication of the model when necessary.

A useful approach when you are planning a sequence of lessons based on a model such as the particle model might be:

1. Teach the original model explicitly – show which part relates to which, making sure students understand and picture it.
2. Test the original model by applying it – students practise using the model to explain simple ideas. For example, explaining why gases can be compressed, liquids can't be compressed, solids are hard, etc.
3. Challenge the original model – by using it to explain more complicated things like melting, dissolving and evaporating.
4. Develop a 'better model' – if necessary explore the development of a better model with the students or provide a more sophisticated one.

Once students have a good understanding of the particle model, this will help them to understand concepts such as why materials have different properties, osmosis, Brownian motion, density, elements, compounds and chemical change.

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Secondary Subject Resources

Science

Module 2 Chemistry

Section 1 Elements, compounds and mixtures

Section 2 Acids, bases and salts

Section 3 Combustion

Section 4 Atomic structures, chemical families and the periodic table

Section 5 States of matter

ENGLISH

TESSA (Teacher Education in Sub-Saharan Africa) aims to improve the classroom practices of primary teachers and secondary science teachers in Africa through the provision of Open Educational Resources (OERs) to support teachers in developing student-centred, participatory approaches. The TESSA OERs provide teachers with a companion to the school textbook. They offer activities for teachers to try out in their classrooms with their students, together with case studies showing how other teachers have taught the topic, and linked resources to support teachers in developing their lesson plans and subject knowledge.

TESSA OERs have been collaboratively written by African and international authors to address the curriculum and contexts. They are available for online and print use (http://www.tessafrica.net). Secondary Science OER are available in English and have been versioned for Zambia, Kenya, Uganda and Tanzania. There are 15 units. Science teacher educators from Africa and the UK, identified five key pedagogical themes in science learning: probing children's' understanding, making science practical, making science relevant and real, creativity and problem solving, and teaching challenging ideas. Each theme is exemplified in one topic in each of Biology, Chemistry and Physics. Teachers and teacher educators are encouraged to adapt the activities for other topics within each subject area.

We welcome feedback from those who read and make use of these resources. The Creative Commons License enables users to adapt and localise the OERs further to meet local needs and contexts.

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TESSA_EnPA_SSCI_M2, May 2016

Contents

Section 1 : Elements, compounds and mixtures

Theme: Probing students' understanding

Learning outcomes

By the end of this section, you will have:

- used an activity to probe students' understanding of definitions of elements, mixtures and compounds;
- planned questions at different ability levels to help students observe and interpret a demonstration related to elements, mixtures and compounds;
- used students' drawings or models to probe their understanding of formulas of compounds and elements.

Introduction

At the end of teaching a topic, teachers usually set a test or exam to find out what the students have learned. They are often dismayed to discover that it is not as much as they expected but by this time it is too late to help students. A good teacher will find out what students understand as they go along, and what the students are finding difficult and help them to make progress.

This unit has three short activities that will fit into your normal teaching about **elements, mixtures** and **compounds** and will show you how to find out what your students understand. Being able to recite definitions of key words like 'element', and 'compound' does not necessarily mean that your students **understand** what they mean. Don't worry – the activities won't prevent you from finishing the syllabus; they are fairly short and will help your students to learn. Once you have tried these activities, you will be able to adapt them when you teach other topics.

1. Teaching for understanding

Students have their own ideas about a topic and an effective teacher takes account of these ideas when teaching. So a good way to start teaching any topic is to find out what your students already know about the topic. You may be surprised about what they have learnt from newspapers, adults, peers, older brothers and sisters and observations. Often their ideas are not the same as the scientific ideas we want them to understand.

In this topic we will start by talking about the chemical elements and how they are the building blocks from which all other substances are made. (**Resource 1** shows the periodic table with all the elements). To find out about the students' ideas, you could ask them if they know what an element is and if they know the names of any of the common elements. They will probably have heard of iron, carbon and sulfur, but there may be others.

Case study 1 shows how one teacher helped her students to understand the definitions of elements, compounds and mixtures. Students need time to think about new words and to understand them. You will be pleased if they can remember and recite the definitions, but you need to be sure that they understand what the words really mean. That is more difficult to measure! You can use the ideas in this unit whenever you introduce new words or scientific terms. In **Activity 1** we represent atoms as circles, and atoms of different elements by different coloured circles. This activity will help students understand these definitions and remember them. Organise the activity so that the students have the opportunity to talk to each other as they work out the answers. Encourage them to explain their answers to the questions.

Case study 1: Group work to probe understanding

Miss Mene had taught her Form 9 class the definitions of 'element', 'mixture' and 'compound', but wanted to make sure that they really understood these key ideas in chemistry. She decided to use a card-sorting activity that would give the students an opportunity to discuss their ideas. She used **Resource 2** to make 12 sets of cards out of some old food packets. Each card had a diagram that represented an element, a mixture or a compound. It took quite a long time to make the cards so she persuaded her colleague who taught the next level of junior secondary to help her, and offered to share the resource with her. Miss Mene organized the students into groups of four, giving each group a set of cards. Using the information she had already given them, they had to sort the cards into three piles (elements, mixtures and compounds). Two groups then came together to check each others' piles and discuss any differences. If they disagreed on anything they had to explain their reasons and agree on the answer.

Miss Mene found that they identified the elements, but she had to explain the difference between compounds and mixtures again.

Her colleague had to teach her class a topic on chemical reactions. She borrowed the cards to help her students revise the definitions that they had learned last year. They struggled at first, but the activity really helped them when they started the new topic on chemical reactions.

Activity 1: Think-pair-share

This activity will help you to find out whether your students understand the definitions that you have taught them.

Copy the diagrams on to the board or make one copy for each pair of students (**Resource 2**).

Instruct the students to work in pairs to identify which diagrams represent the elements, the compounds and the mixtures. Tell them they have to be able to explain their choices.

Next, direct each pair to compare their answers with another pair. If they disagree, they have to discuss the example with each other and agree on the right answer.

As they work, walk round and listen carefully to what they are saying. Use questioning to find out whether the students understand the reasons for their answers.

At the end of the activity you can revise the definitions and be confident that they are understood.

2. Using questioning to enhance a demonstration

One of the reasons why chemistry is difficult is that we cannot see the things we are talking about. It is full of abstract ideas. You can help your students to understand chemical words and ideas by using experiments and models to help them develop pictures of things that they cannot see. A popular experiment for teaching about elements and compounds is heating iron and sulfur to make iron sulfide (**Activity 2**). But there are other experiments that you can do, as **Case study 2** shows. While you are doing the demonstration, you can find out if your students understand what they are seeing by asking them a series of questions. It is important to make sure that your questions challenge them. **Resource 3** reminds you about the different types of questions that you should be asking. It is a good idea to plan the questions that you could ask before the lesson. Think about how you will respond to their answers. You could ask several students the same question then ask them to select the best one. You could also ask a follow-up question: 'Why do you think that?'

After the demonstration you can check their understanding by asking them to write a short paragraph about the experiment, using the key words. By letting the students write about the experiment in their own words, you will really be able to see if they understand the key ideas. You could let them read each others' and give feedback.

Case study 2: Demonstrating a mixture

Mr Okumbe did not have any sulfur, but he wanted to use an experiment to help his students understand the difference between a compound and a mixture. One afternoon he set out a demonstration on the distillation process for his Form 9 class (**Resource 4**). He gathered his students around the front bench and showed them the apparatus. The students examined the ink available and recorded its physical properties, e.g. blue in colour, a dark liquid. He then mixed the ink with water in a test-tube and asked the students the following questions:

- What happens to the ink when mixed with water?
- Does the test-tube get warm or cool down?
- What is the colour of the mixture?
- Is it possible to get the ink back from the mixture?

Mr Okumbe heated the mixture in the flask and as it got to the boil, he collected the liquid which passed through the tube into the boiling tube immersed in a beaker of cold water. The mixture was heated until most of the water in the flask evaporated. As the process was going on, he posed questions to the students. He asked some easy questions which encouraged them to watch carefully, but he also asked lots of 'why' questions which made them think. When he asked harder questions, he gave the students plenty of thinking time. Sometimes he asked them to discuss the answer with their neighbour, before volunteering an answer.

At the end of the lesson he asked his students to try and think of other mixtures that could easily be separated. Someone suggested salt water and they started talking about where the salt they use at home comes from and how it can be produced on a large scale. Mr Okumbe explained that along the coast of Kenya and Tanzania, there are many places where salt is produced by evaporating sea water.

Activity 2: Demonstrating Iron and Sulfur

In this activity, you will demonstrate the reaction of iron and sulfur. **Resource 5** explains the details of the experiment. Before the lesson, plan a set of questions that you will ask your students, which will help them to think about the experiment.

Gather your students round the front.

Start with some simple questions:

- What is an element?
- Which one is the metal?
- What is the evidence that this is a metal?

Get your students to make predictions:

- What will happen if I mix them together?
- What will happen if I heat the mixture?

Ask some open ended questions with more than one answer:

- How could I separate the mixture?

Give them time to discuss the answer with their neighbour before they respond.

When you complete the demonstration ask some harder (higher order) questions:

- What has happened?
- How do we know that this is a new substance?
- Can you explain the difference between an element and a compound?

Finally, set them the task of writing a short paragraph about the experiment that includes the three key words – element, mixture and compound.

3. Using pair work to support understanding

Careful questioning, providing opportunities for students to discuss their ideas, and open-ended writing, are all techniques that will help you to find out the level of understanding in your class. Another helpful approach is to get your students to make a model or draw a picture to explain a scientific idea or principle.

As your students develop their understanding of chemical compounds, you will be introducing them to chemical formulas. Chemical formulas provide a universal way for chemists to talk to each other, and it is important that your students understand what they mean. We cannot see the molecules, so making a model or drawing a picture will help your students to imagine what they might look like. **Resource 6** contains some examples of simple formulae that you could use in order to develop your students' understanding of the concept. When your students are working on the activity, it is important that you move around the room and listen to their conversations. You will find out a great deal about their thinking! If they have a problem, ask leading questions rather than just tell them the answer.

Case study 3: Pair work on formulas

Mrs Ogutu of Tiengre Secondary School, Kenya decided to review previous work on chemical symbols and formulas. She spent a brief moment explaining to the students that chemistry knowledge is easily communicated through use of symbols and formulas. She referred to the periodic table poster that the class had made and wrote on the board the formulas of some compounds made from the elements in the periodic table. She set the activity up as a game, asked the students to work in pairs and distributed some pebbles she had collected (she could have used plasticine instead). She told each student to secretly choose three compounds from the board and to model them using pebbles to represent the atoms. Their partner then had to work out the molecules or formulas which the models represented. She gave the students opportunities to repeat the exercise until they gained confidence in identifying the formulas of the compounds and elements.

While the students were working she moved round the classroom watching carefully what they were doing. Mrs Ogutu noticed that Sammy thought the number referred to the atom after the number so he had put water with one hydrogen and two oxygen atoms. She didn't say anything because she wanted to see if the students could work it out for themselves, and so watched carefully. Sammy's partner, Cornelia, was confused at first but realised what he had done. Mrs Ogutu watched as Cornelia explained formulas to Sammy. Just before the end of the lesson, she asked him to make a model of H_2S and was delighted that he got it right.

Activity 3: Interpreting formulas

The aim of this activity is to reinforce what the formulas actually mean in terms of atoms.

Use formulas that your pupils need to know for the exams. Write the formulas of some elements and compounds on the board (**Resource 6** has some suggestions but you could make up your own). Divide the students into pairs and tell each pupil in secret to choose one of the formulas and to draw a diagram to represent it, using circles to represent the atoms. They should then challenge their partners to identify the formula. Ask the students to repeat this several times until they are confident. At the end of the activity, gather the class round the front and ask them which ones they found difficult and what they have learnt from the activity.

You may choose to extend this to discuss how the diagrams and symbols can both be used to represent the reaction between iron and sulfur.

Resource 1: The periodic table

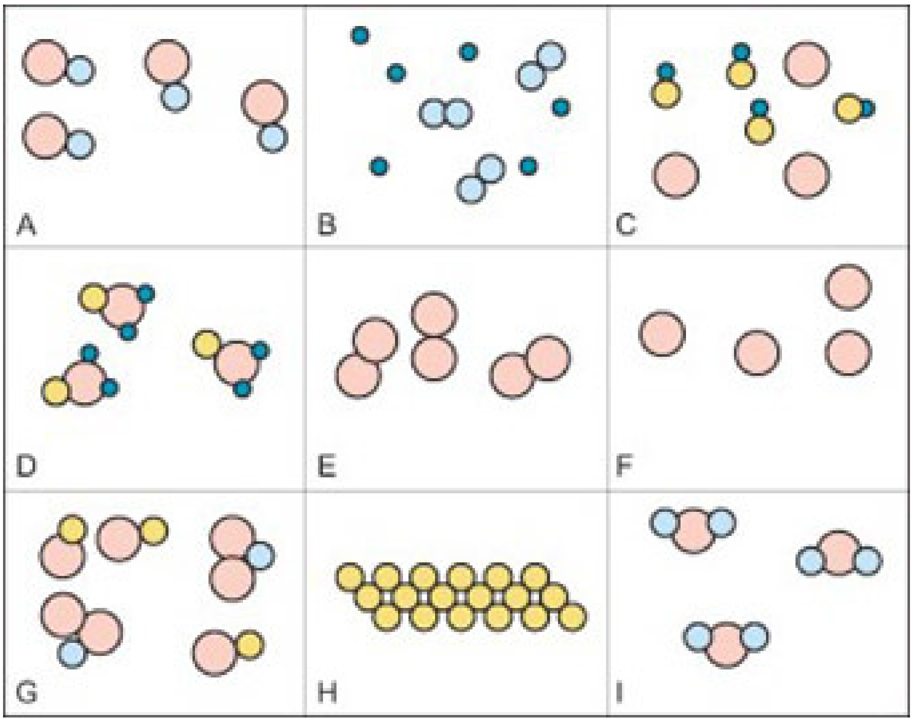
Background information / subject knowledge for teacher

Periodic table

Resource 2: Diagrams of elements, mixtures and compounds

Teacher resource for planning or adapting to use with pupils

Elements compounds and mixtures



Answers – for teacher's use

A. a compound
B. a mixture of two elements
C. a mixture of a compound and an element
D. a compound
E. an element
F. an element
G. a mixture of two compounds
H. an element
I. a compound

Resource 3: Questioning

Teacher resource to support teaching approaches

Questioning

Good questioning is really important and is not as simple as it first may seem. It can help you develop good relationships with your students, it can help your students to organise their thoughts and therefore help them to learn, and it can provide you with valuable insights into their thinking. Good questions can promote thought, encourage enquiry and help with assessment.

By thinking carefully about the sorts of questions that you can ask, you will improve your teaching.

It is helpful to think of questions as being 'open' or 'closed' and 'person' or 'subject-centred'.

Closed questions have a single correct answer. They can reassure students and help you to find out what they remember. But too many closed questions can limit the opportunities to explore thinking and develop understanding. They are often undemanding and can be quite threatening if the student lacks confidence.

Open questions have no right answer, or several right answers. They give you opportunity to find out what your students are thinking, and can be less threatening for some students.

Subject-centred questions ask things like 'what goes into a plant?' and 'what sort of rock is this?'

Person-centred questions focus on the student and are less threatening and more learner-friendly: 'What do you think goes into the plant?' 'What do you notice about the rock?'

A committee of educators chaired by Benjamin Bloom devised a taxonomy of types of questions in which they identified '**lower order questions'** and '**higher order questions'**. Research shows that lower order, recall-type questions tend to dominate classrooms. This leads to an emphasis on remembering facts and reduces the opportunities for creativity, thinking and developing understanding (see table).

It is important that you **plan** your questions appropriately. When you are doing a practical demonstration, for example, or introducing a new topic, write out a list that includes some lower order and some higher order questions. This way, you will be using questions to help your students to learn. Just like every aspect of teaching, you need to practise! You also need to think about how you respond to your students' answers. Try and give them time to think, ask several students the same question or let them discuss the answer before they respond.

Conventionally, students are asked to put their hands up when they answer a question. You probably find that the same students frequently put their hands up and some do so very rarely. It can be very effective to ask specific students to answer your questions and **not** to ask them to put their hands up. Everyone will have to listen as they know that they might get asked. When you first start doing this, make sure that you direct easy questions at students who you know will find the work difficult. If they can successfully answer some of your questions, they will become more confident.

Bloom's taxonomy of questions

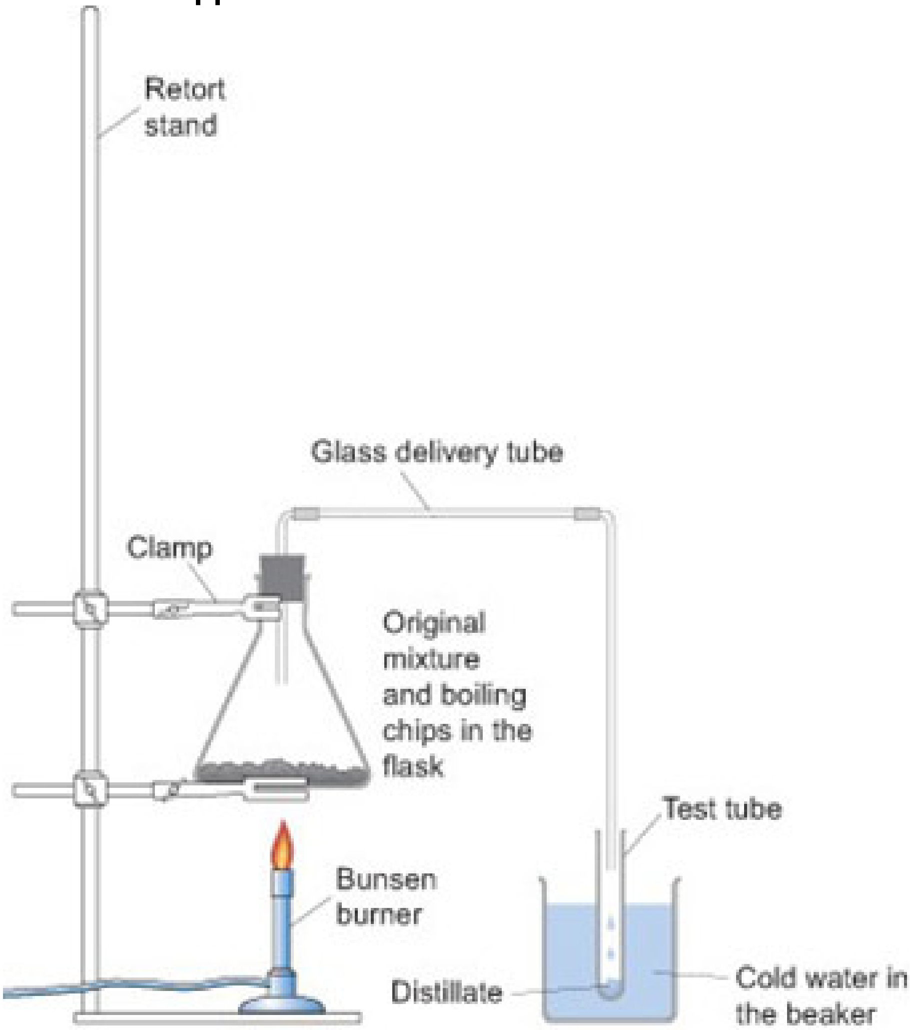
Type of questions	Purpose	Examples
Lower order questions		
Recall	To see what your students remember	Who is? What are? Where are? When did?
Comprehension	To see if your students understand what they can remember	Explain why? What are the differences between? What is meant by?
Application	To see if your students can use their knowledge	How would you classify these invertebrates? What is the evidence that this is a metal?
Higher order questions		
Analysis	To help your students think critically To see if they can make deductions and draw conclusions	Why? What do you think will happen if? What do your results show? What would be the effect on?
Synthesis	To help your students create new ideas from existing information	What would happen if there was no friction? Suppose the Earth rotated at half the speed?
Evaluation	To encourage your students to form opinions and make judgments	How effective is? Which is best and why? What do you think?

Adapted from Amos, S. (2002) 'Teachers' questions in the classroom' in Amos, S., Boohan, R. (eds) *Aspects of Teaching Secondary Science*, London, RoutledgeFalmer.

Resource 4: Distillation apparatus

Teacher resource for planning or adapting to use with pupils

Distillation apparatus



Resource 5: Background knowledge for heating Iron and Sulfur

Background information / subject knowledge for teacher

Using iron and sulfur to demonstrate the difference between a mixture and a compound

Gather your students round the front. Demonstrate the properties of iron (magnetic, sinks in water) and sulfur (not magnetic and floats in water). Mix them together and ask your students to suggest how they might be separated. Based on their responses, demonstrate that it is easy to separate them by using a bar magnet or putting the mixture in water (iron sinks and sulfur floats). When you heat them together, they glow bright red (exothermic) and a new substance (iron sulfide) is formed, which cannot easily be separated.

Heat the mixture in a boiling tube. (If possible use 5.6 g of iron and 3. 2 g of sulfur, or a similar ratio). The boiling tube will glow red as they react. When the reaction has finished, wrap the tube in a towel (to make sure that hot glass does not burn you) and break it with a hammer. Ask students to predict if the substance formed can be separated as before. Ask them to draw their conclusions on the demonstration. Indicate that a new compound has been formed by heating and that it cannot be separated into iron and sulfur.

Reaction between iron and sulfur

Elements, mixtures and compounds

Elements are substances that are made from one type of atom. An element cannot be broken down into any other substance. There are 92 naturally occurring elements and **everything** in the universe is made from these basic building blocks. **Common examples** include carbon, sulfur, oxygen, iron, copper, aluminium. Elements are represented by symbols.

Compounds are substances made from atoms of different elements joined by chemical bonds. They can only be separated by a chemical reaction. **Common examples are** water (H_2O), salt (sodium chloride, NaCl), methane (CH_4). The symbols indicate which elements the compounds contain and the number tells you the ratio in which the atoms of the elements combine.

A mixture is made by simply mixing together elements and compounds. No new chemical bonds are formed. Mixtures can be separated using techniques such as filtration, chromatography, evaporation, magnetisation, flotation and distillation.

Atoms are the basic building blocks. In the activities in this unit, we represent the atoms by circles. By shading the circles differently and drawing them different sizes, we can represent different types of atom.

A molecule is a group of atoms that are chemically joined together. It is possible for a molecule to be an element (e.g. oxygen, O_2) or a compound (e.g. water, H_2O). You can tell the difference because in an element **there is only one type of atom.**

Adapted from BBC Bitesize revision, www.bbc.co.uk/schools/ks3bitesize/science/chemical_material_behaviour/compounds_mixtures/revise1.shtml

How can you tell when a chemical change has taken place?

- A new substance is formed (a compound) which looks different from the starting materials and has different properties.
- There is an energy change – the reaction mixture gets hot or cold.
- It is difficult to reverse the process.

When a compound is formed, a chemical bond is made between the atoms. There are different kinds of chemical bond; covalent bonds as in methane, CH_4,and water, H_2O, and ionic bonds as in sodium chloride, NaCl. The properties of a substance are determined by the type of bonds between the atoms and molecules.

Useful analogies

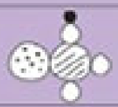
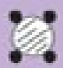
- You can consider the elements to be like the letters of the alphabet. They can be joined together in different ways to give different words (compounds).
- The elements are like bricks. You can join them together in different ways to make new structures.

Other contexts in which you could use these ways of probing students' understanding

- Acids, bases and salts – matching definitions with words, demonstrating how to make a salt, predicting reactions.
- Separation techniques – choosing a method to separate a mixture and explaining why it works.
- Naming pieces of apparatus – matching the apparatus with its uses.
- Physical and chemical change – understanding definitions and classifying examples.
- Chemical bonding – understanding definitions, building models to represent molecules or ionic crystals.

Resource 6: Common chemical formulas

Teacher resource for planning or adapting to use with pupils

Suggested formulas to write on the board	Suitable diagrams (students' diagrams may differ in arrangement of atoms, but should contain the correct number of each atom).
CO_2	
NH_3	
H_2	
Ne	
CO	
$NaHCO_3$	
H_2O_2	
CH_4	

Key

= Carbon
= Oxygen
= Nitrogen
= Hydrogen
= Neon
= Sodium

Return to Science (secondary) page

Section 2: Acids, bases and salts

Theme: Making science practical

Learning outcomes

By the end of this section, you will have:

- organised students in small groups to carry out scientific investigations;
- set up a 'circus' of short experiments (a laboratory parade) to illustrate neutralisation;
- organised children into groups to collect data and present it appropriately.

Introduction

Practical work is a really important part of being a scientist and can help students to learn. There a lots of different types of practical work including demonstrations; investigations in which students plan, carry-out and analyse their own experiment and experiments designed to help students learn specific skills or understand scientific ideas. Gaining first hand experience of materials, organisms and processes can increase understanding and assist retention of knowledge. Shared experiences and real objects may also be helpful for students who find English difficult. All practical work requires careful planning and some improvisation. In this unit the activities are all linked to the topic **acids, bases and salts**. They involve students taking part in an open-ended practical investigation, a circus of short experiments and a practical activity designed to illustrate theory in which they are required to make very careful observations. The activities should fit into your normal teaching. They describe ways of organising familiar experiments that put the students at the centre of their learning.

1. Organising group work to make and evaluate an indicator

Sometimes, especially when they are learning a specific technique, students will need detailed instructions about what to do. However, if they are going to develop an understanding of what it means to be a scientist and the confidence to think for themselves, then you need to give them the opportunity to take part in open-ended investigations. During the planning, carrying out and evaluating of an experiment your students will really have to think about what they are doing and why they are doing it. Extracting an indicator from a plant is a good opportunity to let your students think for themselves. They need to know examples of acids and alkalis, but they are unlikely to be asked to describe the method in great detail. If they don't do quite as you expect then it doesn't really matter; they will get a great deal of satisfaction from working it out for themselves.

It is likely that some of your students will have heard of the term 'acids'. The first activity describes an experiment in which they will make an indicator from flower extracts and use it to test different substances. This topic is a good opportunity for you to 'let go' and take a risk! You will show them what to do, but not give them detailed instructions (**Resource 1** provides some background for the teacher and **Resource 2** explains the importance of doing a risk assessment). Leave them to plan the details in their groups. They will get the most out of this sort of activity if you give them the opportunity at the end to think critically about what they did and how they could have done it better.

Case study 1: Groups plan their experiment

Mr Otieno, a student teacher at Achego Secondary School, prepared a class practical and evaluated it for one of the assessments tasks on his BEd (Science) course. In a previous lesson, the class had tested various household substances with litmus. Now he wanted them to make their own indicator. On Monday morning, Mr. Otieno walked into class with a bundle of leaves and flowers from different plants. He gathered the class round the front and showed them how to extract the colour from a plant. He asked the students to form six groups of about seven students. Each group was to consist of both boys and girls and it had to contain at least two girls. He asked each group to choose a leader. Mr Otieno asked the students to draw a plan for making and testing the indicators from the plant material. The leader had to make sure that everyone had a job. He then asked each leader to come to the front bench to collect a set of flowers (red flowers and blue flowers) and green leaves plus the apparatus they needed.

When the students were working, Mr. Otieno moved from one group to the other posing questions and making sure that everyone was involved – particularly the girls, who he had noticed often hung back.

He asked the students to test the indicators with a variety of household substances and to record their observations in their exercise books. He asked each group to decide which flower made the 'best' indicator and to explain how they decided. Ernest's group thought the red flower was best because it gave a very dark colour. Mary's group thought the blue one was best because there was a big difference between the colour in acid and the colour in alkali. It also distinguished between a weak acid and a strong acid.

Activity 1: Evaluating the experiment

Gather your class round the front. Show them how to make an indicator and test it.

Their task is to prepare at least two different indicators and to use them to test a variety of substances. Divide them into groups and get them to make a plan. They should make a list of the apparatus they need to collect and decide who does what job. Each group should choose a leader. When you are satisfied with their plan they can start. They should make and test at least two different plants. While they are working, you should move around the room and ask them questions about the method.

At the end of the activity give them the chance to look at the samples that other people have prepared. Ask each group to evaluate their experiment.

- Did they get some good samples?
- Did they manage to test several different substances?
- What have they learnt from the experiment?
- Did the leader do a good job?
- Did everyone make a contribution?
- How could they have improved their experiment?
- Did they make efficient use of the time available?

By encouraging them to think about the activity in this way, you will ensure that next time you ask them to work in groups on an open-ended activity, they will do it better.

2. Organising a 'circus' of experiments

Organising a multi-step task in a group is demanding so don't worry if your students were not very efficient. They need practice in working in this way. In the next activity, your students will also work in groups, but this time they will have 8 minutes to complete a task at a 'station' and then they have to move on to the next one. This sort of practical work is helpful if you don't have enough equipment for the whole class to do an experiment at the same time. In **Case study 2**, the teacher uses this sort of activity to organise revision of the topic. **Activity 2** and **Resource 3** show how you could use this method to teach your students some of the everyday examples of neutralisation. In this sort of exercise each station does not need to involve apparatus. Students have the opportunity to talk about the ideas behind the activities, which can be a very powerful way of learning. This sort of activity takes quite a bit of preparation as each station will need an instruction sheet, but when you have done it once you can keep the instructions and use them again. It might not work perfectly the first time you try it, but that doesn't matter. Afterwards, think carefully about what went well and what didn't, so that you can improve on it next time.

Case study 2: A revision circus

Mr Mandela had a few lessons left before his students had to sit the end of term exam. He decided to organise a revision lesson. He set up eight different stations round the room. Each station had an activity from one of the topics that they needed to revise. He chose the activities carefully, so that some of the most difficult aspects of the work were covered. The activities included a card sorting activity, a matching activity for which students had to match definitions and scientific words, some simple experiments (based on reactions they needed to know), a list of simple questions and a past exam question. One of the stations involved some simple practical work: students had to mix some copper carbonate with an acid in a test-tube and write a chemical equation for the reaction. Mr Mandela thought that if they could see the reaction, it would help them remember the equation. He divided the class into groups. He had noticed that when doing practical work, the boys tended to take over while the girls watched. So he divided his class into groups of girls and groups of boys. The students had eight minutes at each station.

Mr Mandela found that the students were very engaged and quite noisy – but they were talking about the activities and arguing about the answers! He moved round the room, providing help if necessary and checking their answers. At the end of the lesson, they had covered a lot of the work and they could not believe that revision could be such fun.

Activity 2: Understanding neutralisation

Before the lesson, set out a number of stations around the room. At each station there should be a set of instructions that the students can follow, making it clear what they have to do and posing some questions (**Resource 3**). Divide your class into groups and send each group to one station. If you have a very large class, you can set up two versions of some of the stations. Make sure they all start together. After eight minutes (you may decide to make it longer or shorter, depending on the activities) tell them to stop work and move them on to the next station. It is important that they all move together. Keep going until each group has visited every station. While they are working you should move around the room and listen to their conversations and maybe ask some questions to make them think. At the end, gather them round the front and ask each group to report on one of the activities. You could finish by asking them to write a summary of what they have learnt in their exercise books.

3. Investigating reactions of acids

One of the reasons that teachers sometimes give for not doing practical work in their classes is that it takes up too much time and they will not be able to finish all the work they need for the exam. But the exam questions often assume that the students have done, or at least talked about, practical work. Having the opportunity to handle equipment and different substances can help students to retain factual knowledge. A carefully designed experiment can be used to illustrate scientific ideas. **Case study 3** and **Activity 3** describe two slightly different experiments, but the principle is the same: the practical illustrates the theory you want them to learn. **Case study 3** involves an experiment that is very relevant to the exam and shows how the teacher helps the students to make the connection between what they are learning in class and the exam questions they will have to answer. **Activity 3** describes a class experiment in which your students make a sample of a salt. In both cases the emphasis is on following the instructions carefully, making observations and working accurately.

Resource 4 provides background for both experiments and **Resource 6** contains some general information about organising practical work.

Case study 3: Observing acids and metals

Mrs Boke was going through Kenya Certificate of Secondary Education Chemistry past examination papers and came across a question on the reaction of metals with acids. She decided to investigate this reaction with her lower secondary class. She assembled a variety of metals available in the school laboratory and within her environs and organised her class into five groups according to ability level. She chose a leader for each group and asked the group leaders to collect the metals and acids from the front bench and distribute them between the groups. Mrs Boke wrote clear instructions on the chalkboard. She asked each group to follow the instructions and add a few drops of hydrochloric acid to the test tube containing the metal. As the students were performing the experiments, she wrote a number of questions on the chalkboard to guide them. For example, does it fizz? How fast does fizzing occur? What happens to the metals? Does the test tube get hot? Does the solution change colour? Do different metals react at the same rate?

After the experiment, she asked the group to record their observations for each reaction and used the observations to determine the rate of reaction of metals with acids.

She asked the groups to construct a reactivity series in their notebooks for the metals tested. She also asked the groups to test for the gas produced. While the students were carrying out the experiments, Mrs Boke spent most of her time with the group with the weakest students to ensure that they followed the instructions, that every student got involved and each recorded the observations in their exercise books.

Towards the end of the lesson, Mrs Boke picked up the chemistry examination paper and read to the class the question on the reaction of metals with acids. The class discussed the question by relating it to what they did in the experiment. Many of the students left the class satisfied with what they had done in the class practical and realised that most of their class activities are relevant to the KCSE examinations.

Activity 3: Think-pair-share to make a salt

When an acid reacts with a base, a salt is formed. Salts are useful substances (**Resource 4)** and your students will need to know how they are made. Before the lesson, write out the steps for the experiment on the board (**Resource 5**). Number each one, but write them in the wrong order. At the beginning of the lesson, ask each student to put the steps in the right order. Then get them to compare their answers with a friend and agree the correct order. Each pair should then compare with another pair and so on, until the class agree on the correct order for the steps. This will ensure that they really engage with the method and are more likely to do the experiment successfully and remember the method. This technique is called 'think–pair–share' and you will find that it is useful in many contexts.

If you have enough apparatus they could perform the experiment themselves, otherwise you could demonstrate the method, getting your students to take part. Make sure you ask lots of questions to keep them interested in the demonstration.

Resource 1: Making indicators from plants

Background information / subject knowledge for teacher

Extraction and testing of flower indicators

A lot of local flowers make good indicators to test for acids and alkalis. You can collect some flowers yourself or ask your students to bring some in. Hibiscus usually works very well as do red, violet, yellow or pink flowers. To extract the colour you can use ethanol, white spirit or petroleum ether. If you don't have those then, for some flowers, hot water will work.

Apparatus per group

Flowers (collected by students or yourself); beaker, jam jar or tin can; 5 test-tubes + rack OR a white plate; mortar and pestle; teat pipette or drinking straw to add drops; candle spirit burner or Bunsen burner; tripod stand or improvised support for the beaker or can; glass rod or stick for stirring; 5 test solutions (e.g. wood ash solution, sodium hydroxide; lemon juice; hydrochloric acid; water; cleaning fluid, vinegar, bicarbonate of soda, toothpaste). For each of the substances, mix them with a few cubic centimetres of water.

Instructions

- Pick some flowers from one type of plant.
- Tear or cut them into small pieces.
- Put them into a tin or beaker or mortar and pestle. Add about 10 ml of solvent.
- Grind the petals until the liquid stops getting darker and decant the liquid into a test tube. This is the indicator.

DO NOT HEAT the spirit as it is highly flammable. Keep it away from naked flames.

- If you don't have a suitable solvent:
    - Place the petals in a beaker or a tin can.
    - Warm the beaker. Stir until the water becomes a deep colour. This is the indicator.
- Pour the solutions you are testing into five different test tubes.

  OR

  Put a large drop of each solution you are testing onto a white plate. Make sure they are as far apart as possible.
- Add drops of the indicator to each solution you are testing.
- Note the colour the liquid goes in acids, alkalis and neutral solutions.

Notes for teachers

- See Risk assessment – Resource 2 .
- If the flower is large (e.g. hibiscus) one or two will be enough. More flowers will be needed if they are small.
- Ensure some groups do hibiscus or other local flowers that you know give good results. Bougainvillea does not dissolve and will need ethanol or another colourless spirit to extract the colour.
- You can filter or decant to separate the flower pieces from the solution, but this is not necessary.

Resource 2: Risk assessment

Teacher resource to support teaching approaches

Risk assessment

When teachers do practical work they should consider the hazards of the experiment and risks linked to the group of children in the room. They should then consider safety precautions and the instructions they give to students. Every time you do practical work you must consider all the potential hazards and take the necessary precautions.

- If available, students should always wear safety goggles. If they are not available, you need to use very dilute solutions. The most dangerous chemical as far as eyes are concerned is sodium hydroxide. Above 0.5M it can cause permanent eye damage. Students **must not** use sodium hydroxide that is stronger than 0.1M, without safety goggles.
- In chemistry it is helpful to be able to heat chemicals. If you are able to do experiments using heat, you must have a fire extinguisher, a bucket of water or a bucket of sand available. Liquids that are very flammable should only ever be heated in a water bath.
- You need to have drinking water, running water (or a large bucket of water) and a first aid kit available if you are dealing with chemicals or glass.

Common laboratory accidents include:

- **Chemicals in the eye**. You must wash the student's eye with large amounts of cold water.
- **Burns.** The area of skin that is burnt should be held under running cold water for at least 10 mins. If it still hurts, soak a paper towel or tissue in cold water and tell the student to hold the wet pad on the affected area. If it forms a blister, you will need to seek medical attention.
- **Chemicals on the skin.** If you limit your experiments to dilute solutions, the danger is irritation rather than blistering or burning. Wash the affected area with quantities of cold water. Do not be tempted to treat an acid burn with alkali or vice versa – you might make the situation worse.
- **Splashes from demonstrations.** When you do a demonstration, think carefully about how you position the students. Don't let them get too close. If you have safety goggles, make sure the students are wearing them, especially if the solutions are stronger than 0.1 M.
- **Chemicals in the mouth.** If students are handling chemicals, they might spill them on their hands and then put their hands in their mouth. If this happens they should wash their mouths out with lots of water.
- **Cuts for broken glass.** If a student cuts themselves, the affected area should be raised above their heart to stop the bleeding, washed with clean water and covered with a plaster. If possible antiseptic cream should also be applied.

There are specific hazards associated with individual chemicals. The hazards are well documented and you should consult an experienced teacher, your university tutor or an appropriate manual whenever you do an experiment.

Resource 3: Neutralisation circus

Background information / subject knowledge for teacher

Neutralisation circus

Suggested stations – instructions for the teacher

1. **Universal indicator** – acid, 10 ml measuring cylinder, beaker, universal indicator, spatula or teaspoon, baking soda, stick or glass rod.
2. **Insect stings** – a beaker of acid labeled ‘insect sting’, test-tubes in a rack, universal indicator, three beakers labeled ‘remedy 1’ (containing baking soda), ‘remedy 2’ (containing vinegar or lemon juice) and ‘remedy 3’ (containing sugar), spatulas or teaspoons.
3. **Indigestion** – two different types of indigestion (anti-acid) tablet, mortar and pestle (or spoon and plate), two beakers (one containing acid), methyl orange indicator, teat pipette, glass rod or stick to stir.
4. **Neutralisation** – a bottle of acid and a bottle of alkali or approximately the same strength, beaker, 10 ml measuring cylinder, universal indicator, teat pipette, stirring rod.
5. **Lemon juice** – several lemons, baking powder, teaspoon, the names of the chemicals involved on separate pieces of paper or card, some ‘+’ and ‘→‘ signs and a piece of paper with some word equations written out (just the reactants) for the students to complete.
6. **Acidic soil** – some soil mixed with citric acid (or any solid acid), spatulas or teaspoons, 10 ml measuring cylinder, test-tubes in a rack, filter funnel, beaker, filter paper, universal indicator, fertiliser 1 (containing sugar), fertiliser 2 (containing lime), fertiliser 3 (containing solid citric acid).
7. **Mix and match** – pieces of card or paper with the numbers 1–14, 14 pieces of paper with the names of colours written on them (or coloured paper if you can get it), 14 pieces of paper with a ranges of substances written on whose pH you hope the students will know – water, hydrochloric acid, sodium hydroxide, lime, lemon juice, etc.

Suggested stations – instructions for the students

1. **Universal indicator** – Pour 10 ml of acid provided into a beaker and add three drops of universal indicator. Add baking soda, half a spatula at a time. Stir after each addition. Record the colours that you see and explain what is happening. When the colour does not change any more, add a few drops of acid. Keep going until it goes back to the original colour. Rinse out the beaker ready for the next group.
2. **Insect stings** – Transfer 1 ml of ‘insect sting’ into a test-tube. Add universal indicator. Add one of the suggested remedies and note the colour change. Repeat until you have tried all the remedies and decide which ones would be suitable to use to remove the ‘sting’.
3. **Indigestion** – Crush an anti-acid tablet and transfer it to a beaker with a few drops of indicator. Add acid, a little at a time, until the indicator remains red. Repeat for a different type of tablet. Which tablet neutralises the most acid?

4. **Neutralisation** – Your task is to find out exactly how much alkali is needed to neutralise 10ml of the acid. Measure out 10 ml of acid, add some indicator and add the alkali very slowly. If you have time, do it twice and take an average of your results. At the end you will compare your results with the rest of the class.
5. **Lemon juice** – Wash your hands. Dip your finger in some lemon juice and put it in your mouth, so that your mouth has an acid taste. Lick your finger and dip it into some baking powder. Place your finger on your tongue. What do you taste? Can you explain what has happened? Arrange the words provided to make a word equation for the reaction. If you have time, try some more word equations.
6. **Acidic soil** – Place 1 spatula of soil in a test tube, add 10ml of water. Place your finger on the end and shake the tube. Filter the solution, or let it settle and pour off the liquid. Add a few drops of universal indicator. Divide the solution between three tubes and add one spatula of fertiliser to each one. Which fertiliser would be best for neutralising the soil?
7. **Mix and match** – Place the numbers of the pH scale in order on your desk. For each number, add a colour and an example of a substance with that pH. Check your answers. Which ones did you get right?

Resource 4: Reacting acids and metals

Background information / subject knowledge for teacher

Reacting metals and acids

You will of course know that metals differ in their reactivity. This is illustrated by the reactivity series, which is usually displayed as a league table with the most reactive metal at the top. Usually we regard a metal as reactive if, when it is added to acid, it produces lots of bubbles and the temperature of the acid solution increases.

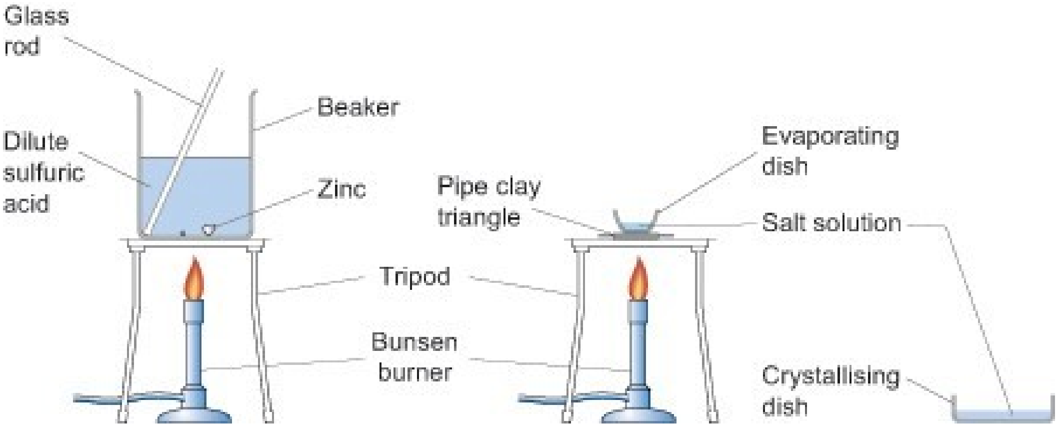
Common metals for reacting with acids (in order of reactivity) would be magnesium, zinc, iron, tin and copper; i.e. one from the top, three from the middle and one from the bottom of the reactivity series. Magnesium is reactive enough to show significant effervescence without being dangerous, copper is unreactive but not expensive as are silver and gold.

All of the metals above hydrogen in the reactivity series will, produce hydrogen gas from acids. However, the reactions become progressively less vigorous as you go down the reactivity series. The choice of acid is usually hydrochloric acid of concentration 1 mol dm^{-3} but some metals react better with sulfuric acid; e.g. zinc. Iron reacts but only very slowly. Tin also reacts so slowly that it is difficult to see the reaction. **Concentrated acids should not be used.**

magnesium	+	hydrochloric acid	→	magnesium chloride	+	hydrogen
$Mg_{(s)}$	+	$2HCl_{(aq)}$	→	$MgCl_{2(aq)}$	+	$H_{2(g)}$
zinc	+	sulfuric acid	→	zinc sulfate	+	hydrogen
$Zn_{(s)}$	+	$H_2SO_{4(aq)}$	→	$ZnSO_{4(aq)}$	+	$H_{2(g)}$
iron	+	hydrochloric acid	→	iron(II) chloride	+	hydrogen
$Fe_{(s)}$	+	$2HCl_{(aq)}$	→	$FeCl_{2(aq)}$	+	$H_{2(g)}$
tin	+	hydrochloric acid	→	tin(II) chloride	+	hydrogen
$Sn_{(s)}$	+	$2HCl_{(aq)}$	→	$SnCl_{2(aq)}$	+	$H_{2(g)}$

Copper is below hydrogen in the reactivity series and will therefore not displace dilute acid so there is no reaction.

As you can see from the above equations the reactions produce salts. You can introduce your pupils to the reactions of metals with acids in one lesson to establish the fact that some displace hydrogen from acids, by collecting and testing for the gas with a lighted splint, and then, perhaps, extending their understanding by isolating one of the salts in the next lesson. For example, zinc granules will react with dilute sulfuric acid (0.5 mol dm^{-3}) to produce zinc sulfate which can then be isolated by crystallisation by evaporating off the excess solvent in an evaporating basin as shown in the diagram below. If you decide to use zinc and sulfuric acid to make a salt, then adding a few drops of copper sulfate will speed the reaction up.



Health and safety

Obviously this experiment involves heating so **great care** needs to be taken when handling apparatus which should be left for a sufficient time after heating for them to have cooled down.

Arrange the class so that pupils work in pairs or small groups. No pupils should be seated if they or members of their group are heating anything.

When heating the evaporating basin the Bunsen flame should be blue but the gas tap adjusted so that there is a *low* flame for gentle heating. When the water level in the basin has been reduced by about a half place a glass stirring rod in the solution and then hold it up to cool. If small colourless crystals begin to form on the rod stop heating and allow the basin to cool naturally. If no crystals form continue heating until they do. Do not continue heating past the point at which crystals are observed at the edge of the solution.

1. 0 mol dm^{-3} HCl is a low hazard at this concentration.

0.5 mol dm^{-3} H_2SO_4 is an irritant at this concentration.

Resource 5: Making Salts

Background information / subject knowledge for teacher

Making salts

Salts are very useful chemicals. Here are some that you and your students might have come across:

- sodium chloride – table salt used for flavouring food
- ammonium nitrate – fertiliser that provides nitrogen
- calcium sulfate – plaster of Paris
- magnesium sulfate – Epsom salts, a laxative
- iron II sulfate – used in iron tablets (to treat anaemia)
- monosodium glutamate – food additive
- potassium nitrate – used in explosives
- copper sulfate – used in agriculture as a fungicide
- calcium citrate – food additive (preservative).

Making a salt from an acid and a carbonate

Here are the steps for the experiment in the correct order:

1. Measure 25 ml of 0.5 M sulphuric acid or hydrochloric acid into a beaker
2. Use a teaspoon or spatula to add copper carbonate. Stir after each addition.
3. Add the solid until the fizzing stops
4. Filter the mixture to remove unreacted copper carbonate (or decant the liquid into an evaporating basin).
5. Heat the solution until crystals just begin to appear.
6. Leave the solution to cool.
7. Pour off the liquid and dry the crystals between pieces of filter paper (or tissue paper).

Resource 6: Practical Work

Teacher resource to support teaching approaches

Practical work

Introduction

Practical work is an important part of learning about science and learning to be a scientist.

The TESSA materials consider practical work in science involves pupils finding out, learning and verifying through observation and experiment, using skills and methods that are used by scientists in the real world. There are different types of practical work, which serve different purposes. Over time, a good teacher will make sure that their students experience different types of practical work.

Purposes of practical work

Different types of practical work and particular experiments will meet different objectives, but the benefits of practical work include:

- Developing practical skills and techniques such as how to use a microscope.
- Gaining first hand experience of materials, organisms and processes that may increase their understanding of science and help the retention of knowledge.
- Developing inquiry skills, such as control of variables, analysis and recording of data and looking for patterns.
- Motivation and enjoyment.
- Encouraging and promoting higher levels of thinking. Pupils can be asked to predict and explain when presented with problems and phenomena.
- Communication skills. Practical work may provide a context for the development of communication skills. The link to shared experiences and real objects may be very helpful for learners with limited proficiency in English.

Types of practical work

- **Demonstrations** – A teacher may decide to do a demonstration for reasons of safety or due to lack of time or resources. They may also be the most suitable method for consolidating understanding or providing challenge. Try to actively involve pupils through questioning or through participating in conducting the experiment or activities before or during the demonstration (e.g. predicting if statements are true or false and then using observations to confirm or change their decision).
- **Structured practical** – Pupils do an experiment in groups. The teacher may give them instructions to follow, advice on recording and analysis and questions to help them relate their observations to theory. These may be suitable for practising skills and techniques, supporting particular inquiry skills, and gaining experiences.
- **Rotating (circus) practical** – Pupils in groups move from one experiment to the next at 'stations' in the classroom. The experiments should be related and

instructions should be brief. Similar questions at each experiment will help pupils gradually build their understanding of a key concept, e.g. particle theory of matter or adaptation. Some of the stations may include a card sort or problem to solve rather than an experiment.

- **Investigation** – Pupils plan, carry out and analyse their own experiment. They may have freedom to choose what they investigate or the teacher may limit the materials available or specify a topic to investigate. The teacher has a role as a facilitator rather than teacher. They will usually give pupils guidance on 'the scientific method' or carrying out a 'fair test'.
- **Problem solving** – this is similar to an investigation, but pupils have more freedom of approach. It may be a practical problem, such as dropping an egg from the top of a building without breaking it, which can be solved in a number of ways. This can be motivating and a good vehicle for the promotion of communication skills.
-

Organising practical work

Whenever you are planning an experiment, you should try it out yourself before the lesson. Simple experiments are often more complicated than you might think. You will also need to do a risk assessment. This means thinking about the potential hazards and taking steps to reduce them.

When dealing with chemicals other than water, students should wear safety goggles. If safety goggles are not available, you need to use very dilute solutions (0.1 M). The chemical that is most likely to cause permanent eye damage is sodium hydroxide (above a concentration of 0.4 M).

You will need to think about how your students will get the apparatus they need. The things you might consider could include:

- Give them an activity to do at their desks and, while they are doing it, you distribute the apparatus they will need.
- Spread out the different items around the room and ask one person from each group to collect what they need. By spreading it out, you will avoid the potentially dangerous situation of lots of people gathering in the same place.
- Give out the chemicals yourself with a teaspoon on to small pieces of paper that they can take back to their place. This will ensure that they get the right amount and will avoid a lot of mess!

Return to Science (secondary) page

Section 3: Combustion

Theme: Science lived – relevant and real

Learning outcomes

By the end of this section, you will have:

- supported learners to use science ideas to reflect on the fuels that are used in their homes and why certain fuels are better in certain situations;
- organised pupils into groups to plan an investigation to test and compare two common fuels;
- developed students' ability to make links between scientific principles and their everyday lives by considering how electricity can be generated.

Introduction

Science is all around us. Too often, young people see science as something learnt from a textbook that is not relevant to their everyday lives. Activities like baking cakes and growing vegetables and mending a bicycle all involve scientific principles. Making connections between the science they learn in school and the things they do at home can help to reinforce the scientific principles that your students need to learn. It might also help them to understand some of the problems that they and their families face. **Resource 1** gives some strategies that you can use in order to help your students make these connections.

A lot of the ideas in chemistry are abstract and relate to things that we can't see, but there are many connections with the 'real' world. Cooking is all about chemical change; extracting useful substances from raw materials involves understanding the chemical properties of the substances; making new materials and medicines involves understanding how different substances can react together; and the properties of the different materials that we use all the time depend on the way in which the molecules are arranged. In this unit, we have used the topic of combustion to illustrate how you can focus on the real-life applications of scientific ideas, but you could apply these ideas to many other topics.

1. Thinking about common fuels

Students often see science as something that they do at school and not necessarily related to their lives. An effective way of demonstrating that this is not the case is to start with the everyday context and use it to draw out the scientific principles. Asking students about things outside school that are important can get them engaged and interested – especially if some controversy is involved. Most real-life situations are actually quite complicated and it is easy to find yourself talking about chemistry, physics or biology, or even wider issues. This will help to keep your students interested in science and help them to see how science can help them to understand the world.

In this unit, we start with aspects of science that are relevant in the home, and move on to consider issues of wider importance to society. In **Case study 1**, instead of starting with the theory of combustion, the teacher tells her students about something she read in the newspapers. She uses the story to explain the theory of combustion. In **Activity 1**, you are encouraged to start by asking students how they cook their food at home.

Case study 1: Using a news item to stimulate discussion

Mrs Onyango of Egerton secondary school, Kenya realised that her students had heard of and used different types of fuels at home and in school. She asked the class to name different fuels they knew of and found out that almost every student had used one type of fuel or the other. Mrs. Onyango then gathered her class round the front and told them a story (**Resource 2**).

Mrs Onyango asked her students some questions: where might the oil have come from? How is oil processed? What might have caused the explosion? What would be formed when it burnt? She explained that aircraft fuel is produced by distilling oil. The oil is imported from the Middle East, processed and then the kerosene is sent by pipeline to Nairobi airport. She explained that kerosene is a 'hydrocarbon' and asked her students to write a word equation to explain the combustion reaction. She drew the fire triangle on the board. She extended the discussion to other fires and asked her students about the different ways of putting a fire out. For each suggestion that they made, she related their ideas to the fire triangle. For example, putting water on a fire, removes the heat; putting a blanket over a fire, removes the oxygen.

In about 20 minutes, Mrs Onyango had covered some of the important ideas about fuels and combustion. She noticed that the story really helped to keep her students interested. For homework, she asked them to write a set of safety instructions for people working in a filling station, and to include a reason for each rule

Activity 1: Organising a brainstorm

Gather your class round the front and ask them what fuels they use at home. Write the names on the board. (**Resource 3** provides some background information on brainstorming.) The point of this activity is to help your students realise that they already know quite a lot about fuels and combustion. Ask them to tell you any other fuels that they have heard of. Write these on the board as well. Ask them which fuel is the 'best'. Ask several different students and get them to justify their decision. **Resource 4** contains information about common fuels and some questions you might ask to help them decide what makes a good fuel. Divide your class into groups. Write some questions on the board and ask your students to work in groups to answer the questions for each fuel. In some villages, people use charcoal rather than wood. Ask your students why this might be and how charcoal is made. At the end, ask them which fuel is 'best' for cooking.

2. Planning how to test fuels

An effective way to convince students that the science that they are studying *is* relevant to their everyday lives is to perform experiments using substances that are familiar to them. For example, when learning about acids and alkalis, they can test substances at home, such as foods, cleaning materials, toothpaste and soap. They can investigate the properties of metals by using objects from home. For this topic, they can do a proper scientific investigation to compare the amount of heat given out by different fuels (see **Resource 5**). You should choose fuels that are commonly used for cooking such as wood, kerosene, charcoal and liquid petroleum gas (LPG). In **Case study 2**, the teacher has very little equipment, but this does not stop her from helping her students to plan an experiment. **Activity 2** describes an experiment you can do if you have some equipment such as spirit burners, metal cans, a measuring cylinder or jug and some means of measuring time.

Case study 2: Which is best?

Mrs Atieno of Sengera Girls Secondary School, Kenya, wanted to get her students to plan an experiment to test different fuels and compare the amount of heat given out. However, she did not have enough equipment for everyone to do the experiment. She believes that it is important for her students to learn to think for themselves – she wishes she had had that opportunity when she was at school.

She introduced the experiment by asking them which was better, kerosene or wood? Luci suggested kerosene but Jess said wood, because it is much cheaper. Luci argued that that is not necessarily the case, as you need more wood; kerosene has a hotter flame. They agreed to test their ideas by measuring how long it took for a set quantity of water to boil, using a known amount of fuel. Mrs Atieno divided them into groups and gave each group a set of questions to help them plan the detail of the experiment.

She managed to gather enough equipment for a demonstration. She had a tin lid to put some wood on, some mineral wool, a tin can and some wire to make a handle. She made a tripod out of sticks to hang the tin can from, and she had a stopwatch on her mobile phone.

She chose one group to carry out the demonstration and encouraged the other students to ask them questions. She asked them how they could make sure the heat was not wasted and was delighted when Ella suggested putting a box round the experiment to exclude the draughts.

Activity 2: Comparing different fuels

Remind your students that there are many different fuels and that we use different ones for different jobs, but they all release energy when burnt. In this class practical, students will test different fuels and compare the amount of energy they give out. You should choose fuels that they are familiar with and use at home and suggest that they test the fuels by using them to heat water. Divide your students into groups. Write a set of prompt questions on the board and get them to plan their investigation (**Resource 5**). When they have a plan, let them prepare the experiment. You will need to do a risk assessment before the lesson. (See **C2 Making Science practical, Resource 2** .)

Make sure you don't tell them what to do – just keep asking questions. The resource also provides an alternative experiment if you do not have the equipment needed to do an investigation.

3. How do we generate electricity?

Cooking is just one activity that requires energy that usually comes from wood, charcoal or LPG. Many parts of Africa do not have a regular and reliable supply of electricity and this is a problem for industries and hospitals in particular. The most common way to make electricity is to burn coal, oil or gas to generate steam which is then used to drive a turbine. Coal, oil and gas are expensive and eventually they will run out. They also produce a great deal of pollution.

There are alternative ways to produce electricity, other than burning fuels, which your students should be aware of. (Resource 6 provides some background information on how electricity is produced). It is a good idea – especially with secondary school children – to make science relevant to everyday life by introducing them to some of the big issues that face society. The teacher in **Case study 3** gets her students to consider the advantages and disadvantages of alternative sources of electricity. **Activity 3** involves students working in groups to solve a problem.

Case study 3: Working in groups to make a decision

Mrs Asantesked her class if they knew some ways in which electricity could be generated. She collected their ideas on the board. She encouraged them to talk about the problems that often arise. Joseph told them how his father worked at a small hotel and was responsible for the small diesel generator. It keeps breaking down, and last week, the price of diesel was so expensive that the manager cut the number of hours the generator was used. A number of guests had complained!

Then Mrs. Asante gave them some information about the different ways of generating electricity. She had written the information on large pieces of paper before the lesson (see Resource 6) and she stuck them to the walls so they could all see them. She also borrowed some books from a nearby school that the students could refer to. The class had to work in groups and decide which method would be the best in their town or village. She asked them to consider the advantages and disadvantages of each method and to make a suggestion about the method that the government should develop in their region. Each group had to present their ideas to the rest of the class. They chose two people to present the information. They had to say what method they had chosen, why they had chosen it, and what the disadvantages might be.

Activity 3: Comparing diesel and solar power

In this activity students consider the advantages of solar panels over diesel generators. Start by gathering the class around the front and brainstorming the advantages and disadvantages of each method for generating electricity. The solar panels will probably seem much more attractive! However, the initial costs are very high. Resource 6 contains some background information on the approximate costs of each method of generating electricity. Ask the class to work in pairs to work out how long it would take for the solar panels to become cost effective. For older children, you could just write the table on the board and let them work out what to do. Alternatively, you could provide support by asking questions to guide them.

You will find that it takes over 10 years. However, there are other advantages of solar panels, such as electricity is available for more than four hours a day and no pollution is produced in the form of fumes or carbon dioxide. At the end of the lesson, ask each student to write a few sentences explaining what they have learnt from this exercise.

Resource 1: Making science relevant

Teacher resource for planning or adapting to use with pupils

Making science relevant to everyday life

Introduction

The TESSA resources are underpinned by a view that science is not just an activity that is carried out by people in white coats in a laboratory. It not only helps students make sense of the world but it is also taking place all around them. Many everyday activities involve scientific principles. It is important that students get the opportunity to apply their scientific knowledge to an understanding of their own environment and that they understand that the skills they develop in science are relevant to some of the problems they face in everyday life.

Possible strategies

Class discussion

Use local examples where possible, but also encourage students to draw on their own experience in the classroom.

Practical work

- Use local examples and materials, e.g. hibiscus indicator; local minibeasts for work on classification or adaptation; wood and kerosene to compare calorific content of fuels.
- Give students a challenge using scrap materials, e.g. obtain clean salt .

Research projects

Students find information from local newspapers or magazines, or interview adults in the community, e.g. brewers, mechanics or health workers. This could be the basis of a poster, oral presentation or role play.

Making use of the school grounds

Besides the obvious opportunities for ecological investigations, the grounds are a source of teaching examples in other topics, e.g. corrosion, structures and forces. Take pupils to see them or ask them to find examples or collect data for analysis.

Day visits

Visit local industries, agricultural sites or museums. The effective teacher will link this to classroom work both before and after the trip.

Homework

Write about examples of science around them (e.g. chemical change in the kitchen or forces on the football field) or to bring materials to the classroom.

Writing tasks

Use local issues as a stimulus for creative written work, e.g. a letter to a newspaper or radio script on local environmental or health issues.

Discussion tasks

- Interviews – one child could be the 'expert' and the interviewer can ask questions as if it was a news item on the radio.
- Pupils come to a decision about a local issue, e.g. health promotion or energy supply.

You should create a file for yourself and keep any newspaper and magazine articles that you find that contain science or are about scientific issues. Every time you start a new topic, ask yourself how it relates to everyday life and help your students to make those connections.

Resource 2: News item on fuels

Teacher resource for planning or adapting to use with pupils

Benjamin's story

Benjamin Njau lived in Sinai, a large settlement near to Nairobi airport. At dawn one morning he went down to the river to collect water and noticed that the oil pipeline that runs through Mukuru (near the settlement) was leaking – aircraft fuel was pouring out into a storm drain. The pipeline carried fuel from the port of Mombasa to Nairobi airport. Benjamin was unemployed and desperate to find ways of making some money. He ran home and collected two jerry cans which he filled up with oil from the leaking pipeline. He would be able to sell the fuel in the city.

By this time, the word had spread, and many people had gathered to fill their cans. As Benjamin was leaving the area, suddenly there was a huge explosion. He could feel flames on his back as he ran as fast as he could away from the area. He was fortunate. He dropped his cans, but he managed to escape and was not hurt. He found out later that over a hundred people died in the explosion and numerous others were badly injured. A few days later it was revealed that the explosion was caused by a man who was helping himself to the fuel; he discarded a cigarette so he could fill up his can. It was a tragic tale that demonstrates, among other things, the importance of everyone understanding the dangers of flammable liquids.

Notes for the teacher

This story provides a starting point for talking about several different aspects of combustion and fuels with your class. Things to consider could include:

- Refining oil – where did the oil come from in the first place? What had been done to it to turn it into aircraft fuel? Liquid fuels are transported in pipelines – how are solids and gases stored and transported?
- Aircraft fuel is kerosene – a hydrocarbon. In order to burn completely it requires plenty of oxygen. Incomplete combustion produces carbon monoxide and carbon. (Do they ever get headaches if they spend a long time in a room with a kerosene burner? Is there a lot of soot on their kerosene heater at home?)
- Why did the fuel catch fire so easily? Introduce the fire triangle – you have to have heat, oxygen and fuel for a fire. Why are you asked to switch off mobile phones in a filling station?
- What sorts of safety procedures should you take when handling fuels – especially liquids?

Resource 3: Brainstorming

Teacher resource to support teaching approaches

Brainstorming

What is brainstorming?

Brainstorming is a group activity that generates as many ideas as possible on a specific issue or problem then decides which ideas offer the best solution. It involves creative thinking by the group to generate new ideas to address the issue or problem they are faced with. Brainstorming helps pupils to:

- understand a new topic
- generate different ways to solve a problem
- be excited by a new concept or idea
- feel involved in a group activity that reaches agreement.

Brainstorming is particularly useful for helping students to make connections between ideas. In science, for example, it can help them to appreciate the links between the ideas they are learning in class and scientific theories.

As a teacher, a brainstorm at the start of a topic will give you a good idea about the extent and depth of knowledge already held by the class. It will not tell you about individuals' understanding, but it will provide a wealth of collective ideas that you can refer back to as the topic progresses.

How to set up a brainstorming session

Before starting a session, you need to identify a clear issue or problem. This can range from a simple word like 'energy' and what it means to the group, or something like 'How can we develop our school environment?' To set up a good brainstorm, it is essential to have a word, question or problem that the group is likely to respond to. The teacher can gather the class round the board and run the session, or, in very large classes, divide the class into groups. The questions can be different for different groups. Groups themselves should be as varied as possible in terms of gender and ability.

There needs to be a large sheet of paper that all can see in a group of between six and eight pupils. The ideas of the group need to be recorded as the session progresses so that everyone knows what has been said and can build on or add to earlier ideas. Every idea must be written down, however unusual.

Before the session begins, the following rules are made clear:

1. Everyone in the group must be involved.
2. No one dismisses anyone else's ideas or suggestions.
3. Unusual and innovative ideas are welcomed.
4. Lots of different ideas are needed.
5. Everyone needs to work quickly; brainstorming is a fast and furious activity.

Running the session

The teacher's role initially is to encourage discussion, involvement and the recording of ideas. When pupils begin to struggle for ideas, or time is up, get the group (or groups) to select their best three ideas and say why they have chosen these.

Finally:

- summarise for the class what they have done well
- ask them what they found useful about their activity. What did they discover in the brainstorming that they didn't realise before?

Resource 4: Properties of common fuels

Background information / subject knowledge for teacher

Properties of common fuels

Your students will have come across various different fuels (although they might need some prompting). There is no 'ideal' fuel. Different fuels are better for different jobs. Liquid fuels are easy to light, but are therefore quite dangerous. Charcoal is quite difficult to light, but burns with a very hot flame. Each fuel has advantages and disadvantages.

Here are some questions that you could ask your students about the fuels that they are familiar with:

1. What would the fuel be used for?
2. Where does the fuel come from?
3. Is the fuel cheap or expensive compared with others?
4. Is the fuel easy to light?
5. When we have used all the fuel that is available can we replace it?
6. Does the fuel produce lots of smoke and soot?
7. Does the use of the fuel affect the environment? If yes, how?

Here is some background information about some common fuels

Fuel	**Global reserves**	**Approximate energy content/ kJ g^{-1}**	**Effect on environment**	**Practical and safety issues**	**Renewable?**
Wood	Difficult to put a figure on this but if the forests that provide wood fuel are re-planted at the same rate as they are cut down, then such fuel use should in principle be sustainable.	0.15	When forests are managed sustainably in this way the CO_2 absorbed in growing replacement trees should equal the CO_2 given off when the original trees are burned. The *incomplete* combustion of wood can release a mixture of greenhouse gases with a greater overall global warming effect than can be offset by the CO_2 absorbed in growing replacement trees. Wood burning processes need to be	Easy to light Safe to store Ash is produced	Renewable

			made as efficient as possible.		
Petrol/ diesel/ kerosene (crude oil)	Approximately 30 more years	46	Produces carbon dioxide gas, which contributes to the greenhouse effect. The other major atmospheric pollutants are oxides of nitrogen, which contribute to acid rain; carbon particulates and unburned hydrocarbon fuel.	Easy to light Safety issues – has to be stored carefully	Non-renewable
Coal	Approximately 190 more years	35	Contains sulfur as an impurity. This means that sulfur dioxide will also be emitted to atmosphere, which contributes to acid rain.	Hard to light Safe to store Produces ash	Non-renewable
Natural gas (methane)	Approximately 50 more years	54	Produces carbon dioxide and carbon monoxide.	Easy to light Safety issues No ash, but can produce carbon monoxide if not installed correctly	Non-renewable
Biofuels	A major source of bioenergy is alcohol (ethanol) produced by fermenting sugar cane or maize. The alcohol is often blended with conventional	30 (ethanol) 40 (biogas is approximately 50% methane)	Both produce carbon dioxide and water vapour , which are greenhouse gases. However, biofuels are claimed to have a 'neutral carbon footprint' because, theoretically, the plants grown to produce them absorb as much carbon	Easy to light Safety issues No ash or residue	Renewable Renewable

	petroleum to form a mixture known as ‘Gasohol’. Also ‘biogas’ (methane) produced during the anaerobic respiration of manure and biological waste.		dioxide from the atmosphere as is emitted when the fuels is burned.		
LPG (liquid petroleum gas)	Approximately 30 more years	48	Produces greenhouse gases when burnt.	Easy to light Difficult to store – stored under pressure No ash or residue	Non-renewable

Resource 5: Teacher's notes for investigating fuels

Teacher resource for planning or adapting to use with pupils

Prompt questions for the investigation and teacher's notes about the investigation

Questions that you could use to help your students plan an investigation

1. Which fuels will you use and where would you obtain the fuels?
2. What type of containers would you use to boil the water?
3. How much water would you put in the container?
4. How will you time how long it takes for water in each container to boil using different fuels?
5. How much fuel would you start with?
6. How will you measure how much fuel is used?
7. What would be the cost of a quarter of a kilogram (250 g) of each fuel?
8. How will you make sure the energy from the fuel is not wasted?
9. How will you decide which is the best fuel?

Questions you could use to see if your students understand the investigation

- How will you measure the heat produced?
- What measurements will you need to make?
- How will you make sure it is a fair test?
- Why is it important to ensure that it is a fair test?
- How can you make you experiment as accurate as possible?
- How will you record your results?
- How will you decide which fuel gives out the most energy?
- Which fuel do you think will be the best? Why?

You could also get your students to think about where the fuel comes from, is it sustainable and how much pollution is caused by burning that fuel on a large scale?

Teacher's notes

You need to test at least two fuels, e.g. wood and a liquid like ethanol or methylated spirit or kerosene. If you have spirit burners, put the liquid fuel in those and weigh them before and after the experiment to determine the mass of fuel burnt. If you don't have spirit burners, use a teat pipette to measure a known volume of liquid fuel (a few millilitres) on to a piece of mineral wool. (You can use the density to calculate the mass). Break the wood into small pieces and burn a known mass on a bottle top or metal tin lid.

Measure 50 cm^3 (or less if the containers are small) into a tin can. Measure the temperature of the water. Use the fuel to heat the water. Measure the temperature rise when a certain mass of fuel is burnt. If you don't have a thermometer, measure the time taken for the water to boil.

The experiment can be made more accurate by preventing draughts, placing the tin can close to the fuel, etc. The aim is to calculate the temperature rise per gram of fuel burnt so you can make a direct comparison.

Useful equipment:

Wood, ethanol or methylated spirit, tin lids, tin cans, thermometers or stop watch, balance to weigh the fuel.

If you don't have the equipment necessary to do the experiment, then you can burn fuels on a bottle top instead. For each one, get your students to suggest the features of a good fuel. While they burn, they could note down how easy it was to light, the amount of smoke produced, the amount of ash produced, whether it smells, the relative amount of heat given out (wave your hand above the burning fuel), the cost and any safety issues. This will still highlight the main issue: that there are lots of different fuels available and different ones are better for different jobs.

Resource 6: Generating electricity in Africa

Background information / subject knowledge for teacher

Generating electricity in Africa

You can use this information to create some posters that your students can refer to during the lesson.

Africa, as a continent, has huge natural fuel resources.

Fossil fuels include gas, oil and coal. New reserves are being found all the time, but once they have been used up they cannot be replaced. A recent discovery is the presence of gas under the sea bed, off the coast of Tanzania.

Fossil fuels are burnt to produce heat, which is used to heat water to generate steam to drive a turbine. In the process, carbon dioxide and other acidic gases are given off which can cause global warming and acid rain. Also, oil and gas have other uses, as a source of petro-chemicals, so it could be argued that they should not be burnt. However, fossil fuels are relatively cheap and burn to produce a lot of heat.

In addition to fossil fuel resources, the continent has huge potential for the development of alternative energy schemes based on renewable sources of energy.

Geothermal energy

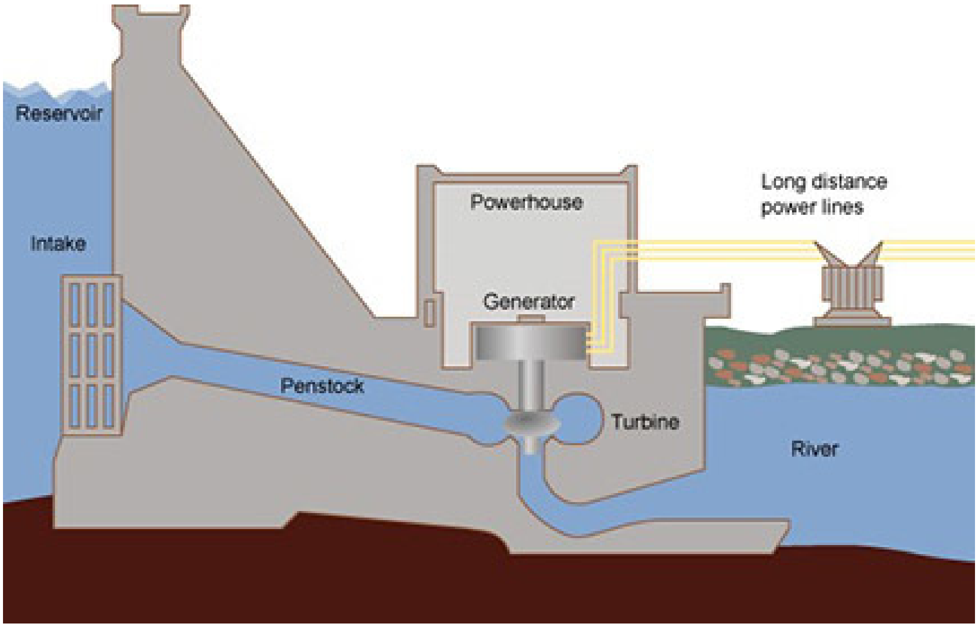
The Rift Valley, which stretches south from Syria to Mozambique, has been targeted by the Kenya Electricity Generating Company (KenGen) as a site for one of the world's largest geothermal energy projects.

The $1. 3bn (£830m) project, to develop 280 MW of geothermal power by 2013, is expected to be backed by the World Bank and will more than double KenGen's geothermal capacity. *http://www.businessgreen.com/bg/news/1804505/kenya-tap-rift-valleys-geothermal-gold.*

In this system, steam-gathering machines are used to drill down into the Earth's crust and the steam that occurs naturally underground in some places (notably places where there are also volcanoes) is brought to the surface and used to drive turbines. There is very little pollution, but the system is expensive to install. It only works in certain places.

Hydroelectric power

Africa also has some of the largest rivers in the world that lend themselves to the utilisation of micro-hydro-power plants. A section through a typical installation is shown below. Hydro electric power uses gravity. Water, falling from a significant height, or flowing fast, is used to drive a turbine which produces electricity.



http://en.wikipedia.org/wiki/File:Hydroelectric_dam.svg(Accessed 2008)

Diagram 1 Hydroelectric dam

In fact, it has been claimed that such installations on the 'Niger, Senegal, Congo, Orange, Limpopo, Volta and Zambezi rivers can generate enough electricity to meet all of Africa's energy needs.' (http://www.desertec-africa.org/index.php?option=com_content&view=category&id=2&layout=blog&Itemid=2)

Wind power

Wind turbines can be installed in areas where the wind is reliable. The wind drives blades which in turn cause a conductor to move in a magnetic field, which generates electricity. They are expensive to build and quite a lot of turbines are needed to produce reasonable amounts of electricity. Some people complain about the appearance and the noise that they make, but they don't produce any fumes or ash.

http://commons.wikimedia.org/wiki/File:Tehachapi_wind_farm_3.jpg (Accessed 2008)

Example 1 Wind farm in the Tehachapi Mountains of California

Solar power

also enjoys a great deal of sunshine and it is solar energy that produces, potentially, the greatest output of electricity through photovoltaic cells and concentrated solar power (CSP). Whereas PV converts the sun's light directly into electricity, CSP concentrates the sun's light, using mirrors that track the trajectory of the sun through the sky from sunrise to sunset, in order to heat water to produce steam that powers turbines and generates electricity. Again, it can be expensive to set up a solar energy plant, but once it is running, the costs are low. Solar panels are also quite delicate and susceptible to damage if not properly installed.
http://africa-charity-project.org/pics/Africa-charity-solar-panels_2.jpg http://news.stanford.edu/news/2010/january4/gifs/solar_panel_news.jpg (Accessed 2008)

Example 3 Solar panels

Many organisations in Africa have small diesel generators in order to compensate for unreliable supply from power stations. These use fossil fuels and therefore produce greenhouse gases.

	Diesel generator	**Solar panels**
Initial price (very approximate)	£1000	£20 000 (to produce 5kW)
Output	5kW/230V	Variable – depends on the number of panels
Cost of diesel	£1. 40 per litre	NA
Amount of fuel used	£1 litre per hour	NA
Advantages	5 kW is enough to run multiple items Relatively cheap to buy and install	No running costs other than maintenance No fuel costs Africa generally has a lot of sun and the sun is overhead Used to charge batteries so electricity is available after dark
Disadvantages	Noisy Can be unreliable if not properly maintained Price of diesel varies Produces CO_2 and fumes	Very expensive to install Fragile – need to be on a roof or fenced in Low wattage produced

Questions you could use to structure the task for children who might need help

If the diesel generator ran for 4 hours a day, how much diesel would be used each day?

How much diesel would be used in a year?

How much would this cost?

How many years would it take reach a total cost of £20 000 (the cost of solar panels)?

Return to Science (secondary) page

Section 4: Atomic structures, chemical families and the periodic table

Theme: Problem solving and creativity

Learning outcomes

By the end of this section, you will have:

- organised students into groups to design a poster to display on the wall;
- supported students in looking for patterns and making predictions;
- introduced your students to some of the problems and issues around the mining of natural resources and encouraged them to think about possible solutions.

Introduction

When your students start to look for a job, the qualifications that they have will obviously be very important. However, potential employers will also be looking for people who are creative and who are able to solve problems; they will be looking for people who can think for themselves. The case studies and activities in this unit are designed to show you how you can give your students the opportunity to be creative and to develop their 'thinking skills'. Some general strategies are given in **Resource 1** . You need to think about how you can create an atmosphere of excitement and enquiry in your classroom. If you can do this, students will ask questions and readily contribute their ideas. Students love dramatic demonstrations and amazing and unbelievable facts and will respond to your genuine enthusiasm about the subjects that you are teaching. Most people are naturally intrigued by the chemical elements so this is a good topic through which to tackle this issue.

1. Creating a stimulating learning environment

Creativity is about the ability to think, not just recall, but to apply, suggest, extend and model and create analogy. You can encourage your students to be creative by setting them open-ended tasks and giving them choices about how they present their work. For example, students who are particularly talented in the humanity subjects and who enjoy writing might like to write about science in the form of a newspaper article or a poem. That would not suit everyone, so that is why giving students a choice can be very helpful. As a teacher, being creative doesn't necessarily involve dreaming up new and exciting activities – although it can do! Creative teachers can take ideas from these units or from their colleagues and adapt them for use in different contexts.

There are lots of1 interesting and fascinating facts about the chemical elements that will interest your students. **Activity 1** will generate material that you could display in the classroom.

Case study 1: Making the classroom attractive

Mr Sibi had just started work in a large secondary school on the edge of a city slum in Kampala. He had very few resources and his classroom was dark and uninteresting. The biology teacher's room was much nicer – she had brought in some plants and there were pictures of living creatures on the wall. Mr Sibi racked his brain about how to make his room more inviting for his students. He realised that chemistry is all around us but it is sometimes hard to spot. He went into the city and persuaded some of the smart hotels to give him the magazines they were going to throw away. He thought of aspects of life affected by the work of chemists and collected pictures to illustrate these, which he displayed in his room. He had sections on fertilisers, medicines, cosmetics, cleaning materials and processed foods.

At college he had heard about the 'Read book project', www.readinternational.or.tz (see **Resource 2**) so while he was in the city he visited an internet café and contacted the project by email. A few weeks later, some chemistry textbooks were delivered to his school and he set up a mini-library in the corner of his room. When he started the topic on the periodic table, he decided to get his students to make posters about the elements to add to his display. They worked in groups, using the books to find information. Each group selected an element and found out as much as they could about it. When they were displayed on the wall, Mr Sibi invited the headteacher to come and judge the posters.

Activity 1: Making posters

Students are usually very interested in the chemical elements. In this activity, they work in pairs or threes to do some research to produce a poster about an element of their choice.

Give them a list of the things you want them to include on the poster (**Resource 2**). If possible you could put a selection of chemistry books from the school library in the room, or borrow some from another school.

They should use the textbook as a starting point. You could give them homework as well and encourage them to collect pictures from magazines or to go to the local library or internet café or to ask people at home who might know something about the elements. They should make their posters as attractive as possible. Encourage them to be creative.

Display the posters on the wall of the classroom and invite the head of science to come and have a look at what your students have done.

2. Supporting students to find patterns

Being able to think creatively and solve problems involves making connections and predictions based on knowledge and understanding. Many scientific discoveries have been made as a result of the creativity of scientists, and the invention of the periodic table is a very good example.

Learning about the chemical elements and the periodic table provides a good opportunity for students to practise making predictions. A good chemist can apply his or her knowledge of a few elements and chemical trends to predict the properties of practically any element. **Case study 2** involves the teacher being resourceful and borrowing a laptop to show students pictures of the reactions. However, if you have access to the chemicals, you should try and show them the real thing. She differentiates the task by asking students of different ability to do slightly different things. **Resource 3** has some general information on differentiation. The story of the periodic table demonstrates how scientists need to be prepared to take a risk and be bold. So in **Activity 2** students hear the story of how the periodic table was invented and have the chance to make predictions just like Mendeleev did. **Resource 4** has some background information to help you.

Case study 2: Patterns in Group 1

When she finished her training, Mrs Sam found a job in a secondary school near to Winneba University. When she was teaching her students about the periodic table, she borrowed a laptop from the university. She went to an internet café and downloaded video clips of the reactions of lithium, sodium, potassium, rubidium and caesium with water. She showed her students the clips of lithium and sodium and asked them to predict how the other metals would react.

She divided the students into groups according to their ability. She encouraged the group of students who found chemistry difficult to describe what they thought they would see in as much detail as possible, whereas she expected some of the other groups to write full chemical equations for the reactions. Later, she showed them the reactions of potassium, rubidium and caesium so they could see if they had predicted correctly.

The group of students who usually struggled with chemistry had done very well and produced accurate descriptions of the reactions. They confidently explained their predictions to the rest of the class. Later on, when they were revising the equations for the exams, even though they found them difficult, this group remembered the lesson and were very motivated to try and understand the equations.

Activity 2: Classifying elements

Divide your class into groups. Give each group a set of cards. Each card has some information about an element. Ask them to devise a way of classifying the elements based on the information on the cards. They will need to be able to explain how they have classified the elements and why they did it that way. After 15 minutes give them the chance to share their ideas with each other. Gather the class round the front and explain how Mendeleev worked out the periodic table (**Resource 4**). Tell them the properties of silicon and tin and ask them to predict the properties of the element that would fit in between them. Finally, tell them the properties of germanium and see how close they were. Explain that a good chemist can use their knowledge of the periodic table to predict the properties of almost any element.

3. Where do elements come from?

Students can sometimes view science as a subject that has absolute answers that can lead to technological advances which, in turn, can be used directly to solve practical problems. In reality, many problems have cultural and economic perspectives that must be considered as well.

Most of the chemical elements are metals. Some of them are very useful and are in great demand. Having metal resources that can be mined, processed and sold is very important for some countries and can bring great wealth. However, if they are mined without due care of the environment or the workers in the mine, then serious long-term problems can be caused. Science can solve some problems – like how to extract a valuable metal from its ore – but can sometimes create new ones.

Case study 3 provides a specific example of an issue that arose in the Democratic Republic of the Congo and **Activity 3** encourages you to let your students research a problem that is specific to your country. While this activity will take the students some time to complete, it does not take up much class time and it will give them an opportunity for independent learning. As a result of their research, they should be able to explain the scientific basis of the process and demonstrate that they understand the issues and problems that can arise. If you have access to libraries or computers these could be used in Activity 3. They will have practice in sorting through a range of information and presenting it in a poster or booklet to their colleagues. You could explain that this is an important way that scientists communicate their research to other scientists at international conferences.

Case study 3: Using a news item to stimulate discussion

Mrs Wambugu gathered her class round the front and read them an article from a newspaper (**Resource 5**). It described some of the problems that have arisen as a result of the demand for a rare metal that is required in the manufacture of mobile phones. Unfortunately this metal is found in an area inhabited by mountain gorillas. When she had read the article, she gave her students the chance to ask questions to make sure they understood the issues.

Then she divided the class into groups. She explained that the situation is obviously very complicated and she asked them to make a list of all the separate problems identified in the article. After about 10 minutes she asked each group for some suggestions and wrote them all on the board.

Finally, with all the class gathered round the front, they discussed some of the possible solutions.

The activity only took about half a lesson, but her students were still talking about it the next day and later on in the term. When they learnt about the different methods for extracting metals from their ores, they asked questions about where the ores came from and how they were mined.

Activity 3: Organising project work

Divide your class into groups of up to four students. Explain that you would like them to identify an issue to research about exploiting natural resources. Give them time in class to decide on the area they will research and to plan how they will carry it out. Access to a library or a computer would be helpful, but also encourage them to talk to their family and other friends to identify a local issue or concern. You could spend a short time with the whole class doing a brainstorming activity to generate ideas for suitable topics. **Resource 6** has some ideas to start the students thinking. Tell them they have 3 weeks to do the research and prepare a poster, a set of leaflets or a scrapbook that will be displayed in the classroom. When they have done this allow them time in the lesson to go round the exhibition and to evaluate each others' work. This is the sort of work that your students could show to a future employer to demonstrate their ability to process information.

Resource 1: Problem solving and creativity

Teacher resource to support teaching approaches

Problem solving and creativity

Through being resourceful and engaging and providing variety, you will be able to motivate your students. If you are willing and able to solve problems and be creative, you will be able to help your students develop these skills. And it is not as difficult as it might seem!

Creativity

Creativity is about the ability to think. It is not just about remembering, but also applying, suggesting, extending, modelling, and offering alternatives. It is something that you can model for your students. Students need to be encouraged to think differently and come up with original ideas. They also need to feel confident in the reception they will get before they make such suggestions.

Some teachers will naturally be very creative, but some will not – and that is fine as long as you are resourceful and willing to try new ideas. A creative teacher, for example, will take the TESSA Secondary Science units and apply the strategies we suggest to different contexts. You could use news items from radio, television or newspapers and relate this to the science you are teaching. You can set open-ended tasks and allow students to make choices about how they present their work. You may take some risks in your teaching. Above all, you will create an atmosphere of excitement and enquiry with dramatic demonstrations, enthusiasm or amazing and unbelievable facts.

Strategies to promote creativity

Get students to:

- write a story to illustrate a scientific principle
- draw a picture to illustrate a scientific principle
- make up a play
- make a model
- take part in a role play (e.g. be the particles in a solid, liquid or gas)
- make up a poem or a rap
- think up alternative explanations for something they see
- write a letter or newspaper article or podcast.

Problem solving

Helping students to develop problem-solving skills is a frequently cited goal of science teachers. As with creativity, you can model these skills in your own classroom. For example, if you can’t answer a student’s question, you can come back next lesson with a solution and explain how you worked it out and why you found it hard. Being able to solve problems involves developing thinking skills. There are various strategies that you can adopt to help children develop these skills (Wellington and Ireson, 2008):

- **Encouraging student-generated questions.** The act of asking questions requires engagement and creative thought, two core cognitive strategies.
- **Being clear about 'purpose'.** Students should be encouraged to ask: what is this all about?' 'What does this relate to?' 'Why do you want us to do this?' – rather than embark on activities in an unthinking, recipe-following fashion.
- **Setting open-ended activities.** Teachers should set activities that can be tackled in a variety of ways so that children have to think about how they will tackle the problem.
- **Planning.** Teachers need to provide opportunities for children to plan their problem-solving strategy in a systematic way.
- **Paraphrasing.** It is well known that you really get to know and understand ideas when you try to teach them to someone else. Giving children opportunity to paraphrase an explanation will help them to understand difficult ideas and to be aware of their own learning.
- **Learning to learn (metacognition).** Teachers can encourage children to become more conscious of their learning by getting them to think about why they don't understand and what strategies helped them that might be useful in the future.

Reference

Wellington, J. and Ireson, G. (2008) *Science learning, Science teaching*. Abingdon: Routledge.

Resource 2: Making posters

Teacher resource for planning or adapting to use with pupils

Chemical families and the periodic table

Your pupils should include all the following information on their poster:

- the name of the element
- the symbol
- a description of what the element looks like, including its state at room temperature and its colour
- where it comes from
- what it is used for
- something about its properties – strength, hardness, reactivity.

They might also choose to include

- the melting point and boiling point
- how it is extracted
- the atomic number and mass number
- the number of protons and neutrons
- an explanation of its reactivity, i.e. why it is very reactive or why it is unreactive.

READ International

It is always easier to give your students the freedom to do activities like this if you have some books that they can refer to. It might be possible for you to borrow books from a neighbouring school, or, if you are in a city, to borrow books from a library.

Read International is a project based in the UK which collects un-used books from secondary schools in the UK and distributes them to schools in Tanzania and Uganda. The books they distribute are carefully sorted and checked to make sure they are relevant to the curriculum. Their contact details are:

info@readinternational.org.uk

READ International, 39–41 Coldharbour Lane, Camberwell, London, SE5 9NR, UK.

If you are not based in Tanzania or Uganda, it might still be worth contacting them to see if they know of other charities who do work in your country.

Resource 3: Differentiating work

Background information / subject knowledge for teacher

Differentiating work for students of varying abilities

As you know, each pupil has different abilities. There can also be a significant difference in age between the oldest and youngest pupil in the class. Some students will learn more effectively by reading a book, some by carrying out a practical activity and some by listening to and absorbing spoken instructions. Some will understand the work very easily, some will take more time. Some will work very quickly through any task you set, some will work slowly. It is impossible for you as a teacher to take all the differences into account all the time, but there are things that you can do to support individuals within a class.

If you have a class of 40 or more pupils this might sound like a daunting task. There are two important things that you need to do to be able to effectively cater for everyone in your class:

1. **Know your students.** You need to give them opportunities to work in groups and listen to their conversations; you need to mark their written work; you need to ask questions of individuals in class and you need to encourage them to ask you questions if they don't understand or just want to know more. When you know who understands easily, who finds science difficult, who likes to talk, who likes to write, who likes to draw and who likes doing experiments, you will be in a much better position to help individuals.
2. **Know your subject.** It is unrealistic to expect everyone to remember and understand everything that you do. Students who find science difficult will be overwhelmed if you try to tell them everything. You need to break each topic down into simple steps and make sure that everyone understands the most important ideas. You also need to know how to challenge students who have grasped the basic ideas.

You can cater for the range of abilities within your group in two main ways:

Differentiating by outcome

This involves setting some questions that get progressively more difficult. Everyone gets as far as they can. Alternatively, you can set open-ended tasks in which students demonstrate what they can do. This also enables you to give them a choice about how they present their work, which can be very motivating. You may find that the degree of support that you need to provide to individuals, pairs or small groups within the class varies significantly.

Differentiating by task

For this, you set different students, or groups of students, different tasks. For example, in a practical session some pupils could have instructions provided for them in written form and some could have them in diagram form and some could have a combination of both.

You could provide a set of questions that cover the basic ideas that you judge that everyone needs to understand and a set that are more challenging. The students who you expect to get a grade A could be given the more challenging ones.

Learning style

There is a lot of research that suggests that different students prefer to learn in different ways. The three learning styles that are more commonly referred to are visual, audio and kinesthetic, i.e. some students prefer diagrams and pictures, some learn best by listening and some prefer to be able to do things.

As a teacher you cannot be expected to cater for all the students all the time, but a good teacher will make sure that their lessons contain activities that cover all three learning styles.

There is a tendency to expect students to do a lot of listening. You should make sure that your students also get to do experiments or activities that involve moving around the room and talking about science. Encourage them to use mind maps and diagrams or pictures to summarise key ideas, rather than simply copying notes off the board.

Resource 4: Resource for classifying elements

Background information / subject knowledge for teacher

Elements

The first elements to be discovered were gold, silver, carbon and sulfur. This is because they occur naturally and are relatively unreactive. Gradually, as people became more interested in science, more and more elements were discovered. Chemists were keen to classify the elements and to understand the similarities and differences between them. They wanted to understand why some are reactive and some are unreactive. All sorts of suggestions were made, but there were always exceptions to the rule and none of the systems suggested were very helpful.

In 1869 a Russian scientist called Dimitrich Mendeleev came up with yet another suggestion. He placed the elements in order of increasing mass. Other people had also done this but it hadn't worked very well. However, Mendeleev had what proved to be a brilliant idea. First of all, he realised that some of the elements were actually quite similar to each other: lithium and sodium for example, and bromine and iodine. He changed the order slightly so the elements which were similar formed a column. This meant that some of the elements were not all in order of increasing mass. He also realised that some of the elements might not yet have been discovered. So he left some gaps in his table. Furthermore, he made some predictions about some of the elements that had not been discovered. He predicted that there would be an element between silicon and tin, and was able to give quite a bit of detail about what he thought this element would be like. A few years later, germanium was discovered and it turned out that Mendeleev had been right! His predictions about its properties were very accurate. Much later, when scientists discovered the proton, they found that Mendeleev had put the elements in order of increasing atomic number.

Mendeleev was obviously a clever scientist but it was his creativity that led to this significant discovery.

Information for Activity 2

Make as many sets of 20 cards as you can, with information about the first 20 elements. (You could print off and cut out the ones below). Each card should contain:

symbol
atomic number
electron arrangement
mass number
appearance
state at room temperature
reactivity.

Give each group a set of cards and ask them to devise a way of classifying them. It does not matter if they don't come up with the 'right' answer – the important thing is that they think about how you might classify elements. Some will sort them into solids, liquids and gases; some will sort them into metals and non-metals. Some might even group them according to reactivity. It is important that you let them devise their own method.

Hydrogen H Atomic No: 1 Mass No: 1 Electron arrangement: 1 Appearance: *colourless, odourless* State at room temperature: *gas* Reactivity: *reactive; reacts explosively with oxygen*	**Helium He** Atomic No: 2 Mass No: 4 Electron arrangement: 2 Appearance: *colourless, odourless* State at room temperature: *gas* Reactivity: *completely unreactive*	**Lithium Li** Atomic No: 3 Mass No: 7 Electron arrangement: 2,1 Appearance: *soft, silvery metal* State at room temperature: s*olid* Reactivity: r*eactive; discolours in air, reacts with cold water, stored in oil*	**Beryllium Be** Atomic No: 4 Mass No: 9 Electron arrangement: 2,2 Appearance: *white, grey metal* State at room temperature: *solid* Reactivity: *does not appear reactive owing to a protective, layer of oxide*
Boron B Atomic No: 5 Mass No: 11 Electron arrangement: 2,3 Appearance: *brown, black* State at room temperature: s*olid* Reactivity: *chemically inert; only reacts with hot, concentrated acids*	**Carbon C** Atomic No: 6 Mass No: 12 Electron arrangement: 2,4 Appearance: *dark grey slippery solid, black powder or glass-like gem stone (diamond)* State at room temperature: s*olid* Reactivity: *reacts with air if heated*	**Nitrogen N** Atomic No: 7 Mass No: 14 Electron arrangement: 2,5 Appearance: *colourless, odourless* State at room temperature: g*as* Reactivity: *unreactive; reacts with oxygen if heated with a platinum catalyst*	**Oxygen O** Atomic No: 8 Mass No: 16 Electron arrangement: 2,6 Appearance: *colourless, odourless* State at room temperature: *Gas* Reactivity: r*eactive; reacts with metals and non-metals – sometimes requires heat*
Fluorine F Atomic No: 9 Mass No: 19 Electron arrangement: 2,7 Appearance: *pale*	**Neon Ne** Atomic No: 10 Mass No: 20 Electron arrangement: 2,8 Appearance: *colourless,*	**Sodium Na** Atomic No:11 Mass No: 23 Electron arrangement: 2,8,1 Appearance: *verysoft,*	**Magnesium Mg** Atomic No: 12 Mass No: 24 Electron arrangement: 2,8,2 Appearance: *silvery*

yellow, pungent smell State at room temperature: *gas* Reactivity: *very reactive; can etch glass*	*odourless* State at room temperature: *colourless, odourless* Reactivity: *completely unreactive*	*silvery metal* State at room temperature: *solid* Reactivity: *very reactive; stored in oil, tarnishes rapidly in air, reacts with water (melts)*	*grey metal* State at room temperature: *solid (often kept as ribbon)* Reactivity: *reacts vigorously with air when heated, slowly with cold water, vigorously with steam*
Aluminium Al Atomic No: 13 Mass No: 27 Electron arrangement: 2,8,3 Appearance: *shiny silver metal* State at room temperature: *solid* Reactivity: *tarnishes in air, forms a protective layer*	**Silicon Si** Atomic No: 14 Mass No: 28 Electron arrangement: 2,8,4 Appearance: *grey, shiny, solid* State at room temperature: *solid* Reactivity: *unreactive*	**Phosphorous P** Atomic No: 15 Mass No: 31 Electron arrangement: 2,8,5 Appearance: *Two forms: red phosphorous (powder) and white Phosphorous (pale grey solid – can be cut with a knife)* State at room temperature: *solid* Reactivity: *white phosphorous ignites in air and has to be stored in water; red phosphorous is unreactive*	**Sulphur S** Atomic No: 16 Mass No: 32 Electron arrangement: 2,8,6 Appearance: *yellow* State at room temperature: *solid* Reactivity: *burns when heated in air; reacts with metals when heated*
Chlorine Cl Atomic No: 17 Mass No: 35 or 37 Electron arrangement: 2,8,7 Appearance: *green, yellowy, pungent smell.*	**Argon Ar** Atomic No: 18 Mass No: 40 Electron arrangement: 2,8,8 Appearance: *colourless, odourless*	**Potassium K** Atomic No: 19 Mass No: 39 Electron arrangement: 2,8,8,1 Appearance: *extremely soft, silvery metal*	**Calcium Ca** Atomic No: 20 Mass No: 40 Electron arrangement: 2,8,8,2 Appearance: *light grey metal* State at room

State at room temperature: *gas* Reactivity: r*eactive; reacts with metals, especially if heated*	State at room temperature: *gas* Reactivity: *completely unreactive*	State at room temperature: *solid* Reactivity: *stored in oil, tarnishes in air, catches fire when it reacts with water*	temperature: *solid* Reactivity: *tarnishes in air, reacts with air on heating*

Resource 5: Mining Tantalum – a controversial issue

Background information / subject knowledge for teacher

Tantalum

Tantalum is a transition metal, required in the manufacture of cell phones. It is mined in The Democratic Republic of the Congo. The result of this mining is threatening the gorillas who live in the forests where the metal ore is found.

What is coltan?

Coltan, short for columbite-tantalite, is a metallic ore comprising niobium and tantalum, found mainly in the eastern regions of the Democratic Republic of Congo (formally Zaire). When refined, coltan becomes a heat-resistant powder, metallic tantalum, which has unique properties for storing electrical charge. It is therefore a vital component in the capacitors that control current flow in cell phone circuit boards.

Mining coltan

Eighty percent of the world's known coltan supply is in the Democratic Republic of the Congo (DRC). Coltan is mined by hand in the Congo by groups of men digging basins in streams by scraping off the surface mud. They then 'slosh' the water around the crater, which causes the coltan ore to settle to the bottom of the crater where it is retrieved by the miners. A team can 'mine' 1 kg of coltan per day. The effect of this is to release mud which can travel downstream and cause the river to silt up and divert underground. In the long term, this can cause serious problems for farmers downstream.

The technology boom caused the price of coltan to increase considerably. A coltan miner can earn as much as US$200 per month, compared with a typical salary of US$10 per month for the average Congolese worker.

Gorillas

Part of the DRC is the last stronghold of the eastern lowland gorilla, which is in drastic decline. There is evidence suggesting that in the last five years eastern lowland gorillas have declined by 80–90%, with just 3000 or so animals left alive. But eastern DRC is a war zone, where factions vie for power across the borders of Rwanda, Burundi and Uganda. The British primatologist, Ian Redmond says: 'To work in the park, the miners have to pay one spoonful of coltan to the military, and one spoon to the local chief. That means about $15. There are about 15 000 people working here, each paying $15 per week to the military who control the region. That's something in the region of $1m a month going into the pockets of the militia.'

Unwittingly, the users of mobile phones and other devices incorporating coltan are contributing to the apes' downfall.

Dr Jane Goodall, renowned for her four decades of work with chimpanzees, says the problem has become acute in the last 10 years, as big logging companies, especially European ones, and miners open up the forests. She says: 'Hunters from the towns go along the roads and shoot everything – elephants, apes, monkeys, bats and birds. They smoke it, load it on to the trucks and take it into the cities. It doesn't feed starving people, but people who'll pay more for bushmeat.'

'The pygmy hunters who've lived in harmony with the forest for hundreds of years are now being given guns and ammunition and paid to shoot for the logging camps. And that's absolutely not sustainable.

The animals have gone, the forest is silent, and when the loggers finally move what's left for the indigenous people? Nothing.'

Questions for your students to consider

The situation in the DRC is highly complex. You could ask your students to analyse the article and identify all the separate problems.

Clearly, there is no easy solution. But discussion will help your students to realise that governance and education are very important in solving problems caused by science and technology.

Some of the problems that they should be able to identify are:

- The method of collecting the ore releases mud which can cause problems downstream.
- The large salaries for the miners mean that they will take risks and this disrupts the local economy. People are less willing to do vital, but low paid jobs.
- Coltan mining removes the vegetation which is destroying habitats and threatening the survival of the mountain gorillas.
- The army take bribes, taking money out of the local economy.
- Nature's balance is being upset, making it difficult for tribes who have lived for thousands of years in the forest to survive. They are being displaced, without a good alternative being available.
- When animals are killed, it can upset the food chain, threatening many species.
- This has a bad effect on the tourist industry. In other parts of Africa, the tourist industry has a very positive effect on the economy.

Resource 6: Elements found in Africa

Background information / subject knowledge for teacher

Elements found in Africa and their uses

(Abbreviations: DRC = Democratic Republic of Congo, RSA = Republic of South Africa)

Element	**Found where (figures in brackets represent the approximate proportion of current world reserves)**	**Uses**
Gold	Botswana (16%) DRC (15%) RSA (7%) Angola (3%)	Jewellery, cell phones, calculators, personal digital assistants, global positioning system units (GPS) and satellites (as a lubricant – in the zero gravity of space oil-based lubricants would volatilise) and other small electronic devices. Most large electronic appliances such as television sets also contain gold. The electronic applications utilise gold's excellent electrical conductivity. Gold is also widely used for dental fillings because of its lack of reactivity.
Aluminium	Guinea (as bauxite, 30%)	Aluminium is by far the most widely used non-ferrous metal: its uses are legion; it has excellent electrical and heat conductivity and strength to density ratio. This last property accounts for its many transport uses, including aerospace. It is also used in packaging; construction, e.g. window frames, roof and wall cladding; electrical transmission cables, cooking pans and utensils, drink cans and ships' masts.
Manganese	RSA (77%)	Manganese is an essential component in many steels; including high tensile steel, which contains between 8 and 15% Mn. Manganese is also used to improve the corrosion resistance of the aluminium used to manufacture food cans.
Vanadium	RSA	Like manganese, vanadium is used mainly in alloy steels to improve their strength, such as high speed tool steel. Vanadium pentoxide is also an important catalyst in the industrial production of sulfuric acid by the contact process.
Carbon (diamond)	DRC (16%) Botswana (15%)	Diamond has a high resistance to corrosion and is the hardest naturally occurring substance known. Artificially produced industrial diamonds are used for applications that make use of the

	RSA (8%)	properties mentioned above; e.g. cutting and drilling tools in mechanical engineering, geological ore processing and crude oil exploration
Copper	Zambia (3. 5%) RSA (0.9%) DRC (0.3%)	Copper has excellent heat and electrical conductivity that explains its major applications in heating systems for pipework and as the conducting medium in electrical wiring. Copper is also alloyed with nickel to produce hardwearing and corrosion resistant coinage. This property also explains its use in roofing and construction; e.g. the Statue of Liberty is clad in copper about 12 mm thick.
Cobalt	Zambia	Permanent magnets. Cobalt is also used in alloy steels to produce so-called ‘super alloys’ that have extremely high strength even at temperatures approaching their melting points. This means that they are widely used in jet engines. The isotope cobalt-60 is a gamma-ray emitter and used in radiotherapy and medical equipment and food sterilisation.
Chromium	RSA (84%) Zimbabwe (3. 4%)	Chromium has extremely high corrosion resistance that explains its use in steel alloying. 14% chromium or above produces stainless steel. Chromium oxide is used in the manufacture of magnetic tape used in cassettes. In the past, chromium compounds were also widely used to make paints and pigments, such as chrome yellow, but are less so nowadays due to concerns about their long-term environmental effects.
Platinum group metals (PGMs) which include Platinum, Osmium, Iridium, Palladium, Rhodium and Ruthenium	RSA (58%)	The PGMs are all extremely resistant to corrosion. This and their bright, attractive lustre, explains their use in the manufacture of jewellery. They all have several stable oxidation states which makes them ideal for use as catalysts in many industrial processes. They are used in the manufacture of motor vehicle catalytic convertors.
Uranium	Namibia (7%) Niger(6%) RSA(1. 5%)	Most uranium is used in the manufacture of nuclear weapon systems and nuclear reactors. However, relatively tiny amounts are also used in medical imaging and smoke detectors. Uranium accounts for about 5% of the world’s non-renewable energy sources.

Questions that your students could consider

- Choose an element (e.g. aluminium, copper) and find out where it is mined and how it is extracted. What are the challenges and opportunities for local people?
- Choose an element that is mined in their country e.g. copper and find out about the history surrounding the industry. What are the lessons for the future?
- Open-cast mining – what is it and what are the environmental implications?
- Gold – what effect does the discovery of a valuable mineral have on a local area? How can the beneficial effects be maximised?
- Galamsey mining has become increasingly common amongst the youth in Ghana and other African countries. What are the dangers and environmental effects of this illegal activity?

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Section 5: States of matter

Theme: Dealing with challenging ideas in science

Learning outcomes

By the end of this section, you will have:

- used an activity to probe students' understanding of the key ideas in this topic that they encountered in primary school;
- organised your class into three groups to act out various scenarios which demonstrate understanding of how particles behave;
- supported students in developing a teaching resource or revision tool in order to link together ideas about particles.

Introduction

Being an effective science teacher involves being able to explain difficult ideas very clearly. There are a number of topics in science that are difficult to understand and difficult to explain. This is because the ideas are abstract and based on things that we cannot see. Students often have ideas that are 'wrong', particularly about the more abstract topics. Just explaining the 'right' idea might work in the short term, but often doesn't last until the student has to take an exam. The 'wrong' ideas need to be identified and tackled before progress can be made. Often, simply explaining the ideas is not enough; you need to revisit them and consolidate understanding.

In this unit, the three activities build on each other and will enable you to help your students gradually develop their understanding. The first activity focuses on literacy and making sure that your students understand the key words. The second and third activities use different approaches to developing understanding. The purpose of the first activity is to find out and reinforce what they already know. The second activity extends their understanding so that they can explain processes such as dissolving, melting and evaporating in terms of how the particles behave. The third activity helps them to consolidate their learning by talking about the ideas and developing a concept map or a mind map.

1. Probing understanding

States of matter is a topic that your students will have learnt about at primary school, but don't assume that they remember everything. They will have met some of the key words before, but some will be new.

In **Case study 1**, the teacher encourages her students to tell each other what they remember. Researchers have established a clear link between language and learning. When students talk about ideas, they have time to draw on their memory of what they have done before. It also helps them to practise using scientific words. You get the chance to listen to what they are saying and look at what they are writing, so that you are aware of their misconceptions (see **Resource 1**). You are far more likely to address their misconceptions in this way. Too often, when we use questions in a whole class discussion, we assume that because one student can give us a correct answer, the class as a whole understands the topic well. **Activity 1** uses 'think–pair–share'. Students work on their own first and then swap ideas with their partner. Each pair then talks to another pair until the whole class is talking. This method works well for students who are not confident about talking in front of the whole class.

Case study 1: Thinking about solids, liquids and gases

Mr Hausa teaches a class of 12-year-olds. Some of the students came from the primary school next door, but some came from different schools. He wanted to find out what they already knew about 'states of matter'. Last year, he did a brainstorm with the whole class, but this year he had a much bigger class. First of all, he gathered them round the front and showed them a mixture of corn starch and water. He asked them whether it was a solid or a liquid (see **Resource 6**), in order to get them thinking. He divided the class into groups of four and gave each group a piece of paper. They had to work together to write down anything they could remember. He asked a few questions to get them going: what is special about a solid? What is it called when a solid turns to a liquid? They could draw pictures if they wanted. If a group was not doing very much then he asked them some more questions based on the primary school syllabus to get them going. While they were working, he went round with the corn starch and water so they could have a closer look. After 15 minutes he collected the pieces of paper. He found out that all the groups knew how the particles were arranged in a solid, but there were some strange ideas about liquids!

Activity 1: Think-pair-share

Before the lesson, write on the board or a large sheet of paper, the terms, definitions and examples given in **Resource 2** . They should be in three columns (word, definition, example), but should be mixed up so that students have to match them up correctly. First ask them to work on their own to match them up correctly. Then they should compare answers with the person next to them.

Each pair should compare their answers with another pair. If they disagree, they have to discuss with each other and agree a set of correct answers. Once the group of four have agreed the correct answers, they should compare with another group, and so on. Eventually, through discussion the students will all agree on a set of correct answers. You should check through questioning that the students understand the reasons for their answers. At the end, individual students should come to the front and draw lines to join up the word with the correct definition and example.

2. Modelling atoms

Difficult ideas can often be helpfully illustrated using a role play. This can make something very abstract feel concrete and can help the students to understand. The danger, of course, is that an inaccurate model can introduce more misconceptions and difficulties at a later stage.

Resource 3 is about modelling in science. When you are using a role play to represent an idea, you should always get your students to explain what they are doing. By identifying the strengths and weaknesses of the model, you will also add to their understanding. The teacher in **Case study 2** has a really big class. This can be discouraging and may put teachers off doing activities like role play. But she has come up with a plan of how to make it work. You could use her idea for other activities that would be difficult to do with a large number of students. **Activity 2** describes a role play that your class should enjoy. You could set it up like a game, with some students acting out a process, and some guessing which process it is. This will make everyone concentrate and think about the ideas.

Case study 2: Working with a large class to do a role play

Mrs Lomwe had 80 students in her class. She was keen to do a role play to help them understand ideas about particles but was not sure how to organise so many students for a role play. She talked to some of the other teachers and between them they made a plan.

Mrs Lowme was fortunate to have some students who were natural leaders. She selected eight students and asked them to stay behind after school one day. She explained the purpose of the role play and that she wanted them to act as group leaders. She did the whole activity with the group of eight and showed them exactly what she wanted them to do. The idea was to get the students to behave as particles and to act out processes such as ‘condensation’ and ‘evaporation’.

The next day, she split the class into four groups, with two of the leaders in each group. Two groups stayed in the classroom, but two of the groups went outside. The leaders had to split their group in half. One half acted out one of the processes while the others had to guess which one it was. Then they swapped over. The students were encouraged to praise or criticise each others’ ‘shows’. If they thought it was good they had to explain why. If they thought it could be improved, they had to explain how. Many thought that the group acting out a liquid could have improved their performance if one or two of the students had left the group, showing that all liquids evaporate. But they liked the way the ‘particles’ kept bumping into each other.

Activity 2: Helping students model atoms

Divide your class into three groups. Draw a large square on the floor with chalk. Ask one group to act out being a solid. Get the other students to say two good things about the performance and one thing that could be improved. Repeat for a liquid and a gas, so each group gets a turn.

Then give each group the name of a process such as evaporation, condensation, freezing, melting or dissolving. Ask them to act out their process. The other groups have to guess which process it is. They have to explain why they think it is that process and say what is good about the performance. Research shows that students find it difficult to explain these processes in terms of the particles. This activity will help your students to understand the processes.

3. Making revision fun

One of the best ways to reinforce learning is to try and explain the ideas to someone else. Some people find that they only really understand a topic when they have to teach it. The same can apply to your students. Copying text and diagrams from the chalkboard will give them a good set of notes to learn, but it will not necessarily help their understanding.

Particle theory is really important and underpins ideas about chemical reactions and properties of materials. It is worth taking a bit of time to make sure that your students understand the ideas and how they link together. It might be helpful for them to produce a teaching resource that would be suitable for younger students or for someone who does not know much science. The teacher in **Case study 3** sets such a task for homework so that it does not take too much time out of the lesson, but she does spend some time getting her students to think about what makes a good resource. Students are more likely to do well, if they know what you are looking for. Alternatively they could produce a resource to help them revise, such as a mind map or a concept map, as in **Activity 3**. **Resource 5** explains some background to concept maps and mind maps.

Case study 3: Preparing a teaching resource

Mr Mumba had ten minutes left at the end of a lesson. He had just finished the topic on particle theory and wanted his students to make a teaching resource suitable for younger children for their homework. He gathered them round the front and explained what he wanted them to do. He suggested that they might make a poster, a leaflet or a small booklet. He asked them how they might judge such a resource. Able, a student, suggested that it should have pictures and diagrams. Lena thought it would be helpful if it had lots of real life examples and Sonia thought it was important to explain all the scientific words very clearly. Mr Mumba made a list of their suggestions on the board. Some children find it difficult to find time to do their homework because they have to do a lot of jobs around the house. So Mr Mumba arranged that anyone who wanted to could stay in the classroom after school to do the homework. Some students went and sat under a tree in the grounds and worked together on their posters. Mr Mumba did not mind; he realised that talking to each other about the ideas would help them to learn. Hari and Vincent made a poster in which Hari drew the diagrams and Vincent did the writing.

Activity 3: Making a mind map

You should explain to your students that one of the purposes of revision is to reinforce their learning. Simply reading through notes is not always as effective as they might think. A good thing to do is to draw a concept map, a mind map or a poster, or to make a summary of the key ideas on small cards or pieces of paper that can easily be carried around in a bag or a pocket. Divide the students into pairs and ask each pair to devise a revision tool that summarises the key ideas about particle theory. You could give them A4 paper or take a double-page from an exercise book to do this. They should be encouraged to use everyday examples to illustrate the ideas, to use pictures and diagrams and to think about how the ideas are linked together. If students understand how the key ideas link together, they will find it easier to remember the details.

Once they have completed the work they should swap with another group and use the evaluation criteria (**Resource 4**) to assess the quality of their work.

Resource 1: Misconceptions surround states of matter

Background information / subject knowledge for teacher

Misconceptions

Children find it very difficult to understand just how small atoms and molecules actually are. A common misconception is that cells and atoms are comparable; in fact cells contain millions of molecules.

One way of introducing the idea of 'magnitude' is to use a football. If you measure the diameter of a football and divide it by 10^8, that gives the size of an atom. If you multiply it by 10^8, that gives the size of the Earth. If you have access to the internet, there is a website called 'powers of ten' which will help you to envisage the magnitude of atoms: http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/.

Children also have misconceptions about the particle model for matter. Some of the common ones that you will find include:

- If a solid or liquid is heated, the particles get bigger. This is not the case. At higher temperatures, they move about more and take up more space, but they do not get bigger.
- Children tend to overestimate the space between the particles in liquids. They regard a liquid as half-way between a solid and a gas. This is not the case. The particles in a liquid are close together, although they are free to move and change place.
- Children confuse 'melting' and 'dissolving'. Some children think that when a solid melts, the particles 'pop' or simply disappear.
- Children find it difficult to accept that most of a gas is empty space.
- Children assume that the particles will have the same properties as the solid, liquid or gas they make up and therefore will explode, contract, expand or change shape.
- When they see a diagram of a molecule such as oxygen (O_2), children think it must be a compound because there are two atoms joined together. They do not always understand that if both the particles are the same then it is an element.

Resource 2: Think-pair-share activity

Teacher resource for planning or adapting to use with pupils

The words, definitions and examples are in the wrong order. Your students need to match them up correctly. You could get them to copy the lists as you have written them on the board and use a pencil to join the word with the correct definition and example. Alternatively, you could ask them to match the numbers and letters and when you have agreed the correct answers, ask them to copy the table with everything in the correct order.

Key word	Definitions	Example
1. melting	A. changing from a gas to a liquid	S. sugar disappearing into water
2. evaporation	B. the liquid in which a solid dissolves to form a solution	T. when molten iron solidifies
3. dissolving	C. changing from a solid to a liquid	U. water changing to water vapour
4. solution	D. a solid that dissolves in a liquid to make a solution	V. salt water
5. solute	E. changing from a liquid to a gas	W. when steam forms water on a cold surface
6. solvent	F. the mixture formed when a solid 'disappears' into a liquid	X. the salt in salt water
7. condensation	G. changing from a liquid to a solid	Y. ice changing to water
8. freezing	H. when a solid is mixed with a liquid and seems to disappear	Z. the water in salt water

Resource 3: Using models in science

Teacher resource to support teaching approaches

Using models in science

Using models or analogies is a very powerful way of helping children to understand scientific ideas. Used properly, models can also help to develop critical thinking. You can do this by helping children to evaluate the strengths and weaknesses of a model.

Some general principles to think about when planning lessons with models are:

- introduce the model early in the teaching of the topic, then use the model consistently until it is replaced by a more sophisticated one
- ensure students make links between the model and the real situation
- ensure students recognise the differences between the model and what it is illustrating
- encourage students to apply their understanding to explain new ideas
- encourage students to identify strengths and weaknesses in any model
- increase the sophistication of the model when necessary.

A useful approach when you are planning a sequence of lessons based on a model such as the particle model might be:

1. Teach the original model explicitly – show which part relates to which, making sure students understand and picture it.
2. Test the original model by applying it – students practise using the model to explain simple ideas. For example, explaining why gases can be compressed, liquids can't be compressed, solids are hard, etc.
3. Challenge the original model – by using it to explain more complicated things like melting, dissolving and evaporating.
4. Develop a 'better model' – if necessary explore the development of a better model with the students or provide a more sophisticated one.

Once students have a good understanding of the particle model, this will help them to understand concepts such as why materials have different properties, osmosis, Brownian motion, density, elements, compounds and chemical change.

Resource 4: Marking criteria for posters

Background information / subject knowledge for teacher

Marking criteria

When you mark questions about scientific topics, it is easy to decide if it is right or wrong. You might correct the answers, or ask your students to correct them themselves. Whatever you do, you should make sure that you provide some feedback so that your students know how to improve.

Teachers sometimes don't like setting open-ended tasks or project work because it is much more difficult to mark. However, these sorts of activities will help your students to learn and they will tell you a lot about your students.

To make it easier to mark projects, leaflets or posters, you need a set of criteria – things that you think are important. You should share the criteria with your students so they understand what is expected of them. You could even get them to suggest suitable criteria.

Once the criteria are clear, then you can mark the work – or you can encourage them to mark each others'. They will need to do this a few times to get used to it – but they will get better at it. At first, encourage them just to give positive feedback: 'I liked the way you have ...' or 'You have made that really clear ...' As they get more used to looking at each others' work, they might be able to suggest improvements: 'I really like the diagram that shows melting – it would have been good if you had done one for dissolving as well.'

Possible criteria for assessing a teaching resource, a leaflet or a poster:

- Is the information clearly laid out?
- Is the information presented logically so it would help the learner?
- Is the text well written?
- Have they made good use of diagrams?
- Are the key words clearly defined?
- Is the information scientifically correct?
- Is there evidence that the work is carefully planned?

For project work you might include:

- Is there evidence of independent research?
- Is the project clearly structured?

Resource 5: Revising with mind maps and concept maps

Teacher resource to support teaching approaches

Revision tools

Students find revision quite difficult. They will probably have an exercise book containing notes. One technique is to read through the notes and to try and remember them. However, this is not always effective. It can be difficult for students to concentrate when reading – especially if English is not their first language.

More active approaches to revision include making summaries on posters or on small cards (or small pieces of paper) that can easily be carried around. Students can invent questions and then work in pairs to test each other on the work. Two particular approaches are **concept maps** and **mind maps.**

Concept maps and mind maps are tools which help learners visualise a topic.

A concept map is a hierarchical diagram which shows the relationships between concepts. The concepts are usually represented by circles or squares. The shapes are connected by lines or arrows. Words on the arrows provide linking phrases, such as ‘leads to’, ‘results in’, ‘includes’, ‘necessary for’ or ‘shows’. Drawing a concept map is a good way of organising your thoughts. It helps you to understand how concepts are linked together and sometimes to see connections between concepts that you hadn’t thought of before.

A mind map is a diagram in which ideas and words are arranged around a key central word or idea. Mind maps can be put together quickly, often as a result of a brainstorming session. They can be very helpful for revision, especially for people who learn more easily by looking at pictures.

Mind maps and concept maps are only really helpful for the person who drew them. It is often the process of drawing them that is more helpful than the finished product.

Both techniques are helpful for revision.

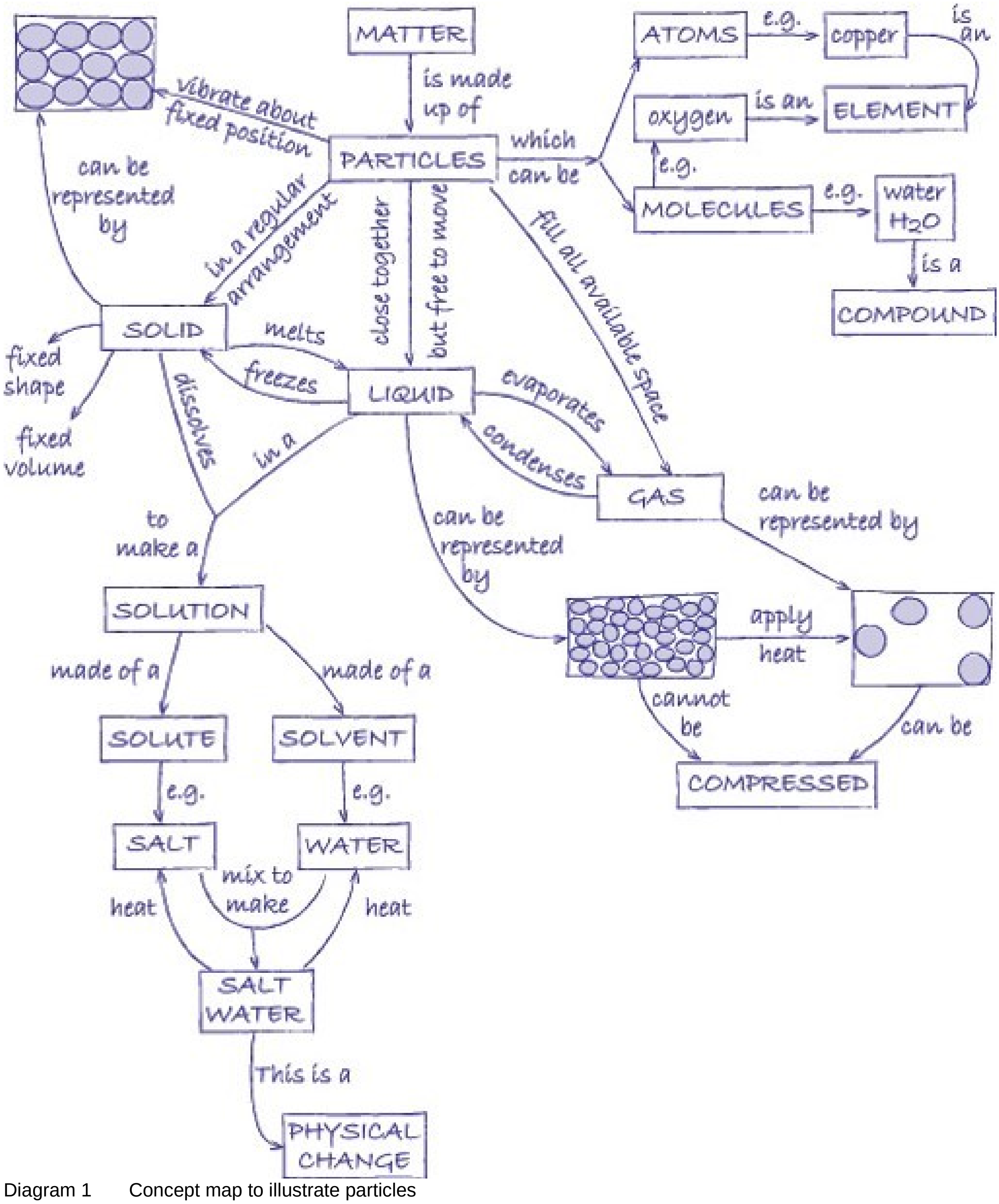

Diagram 1 Concept map to illustrate particles

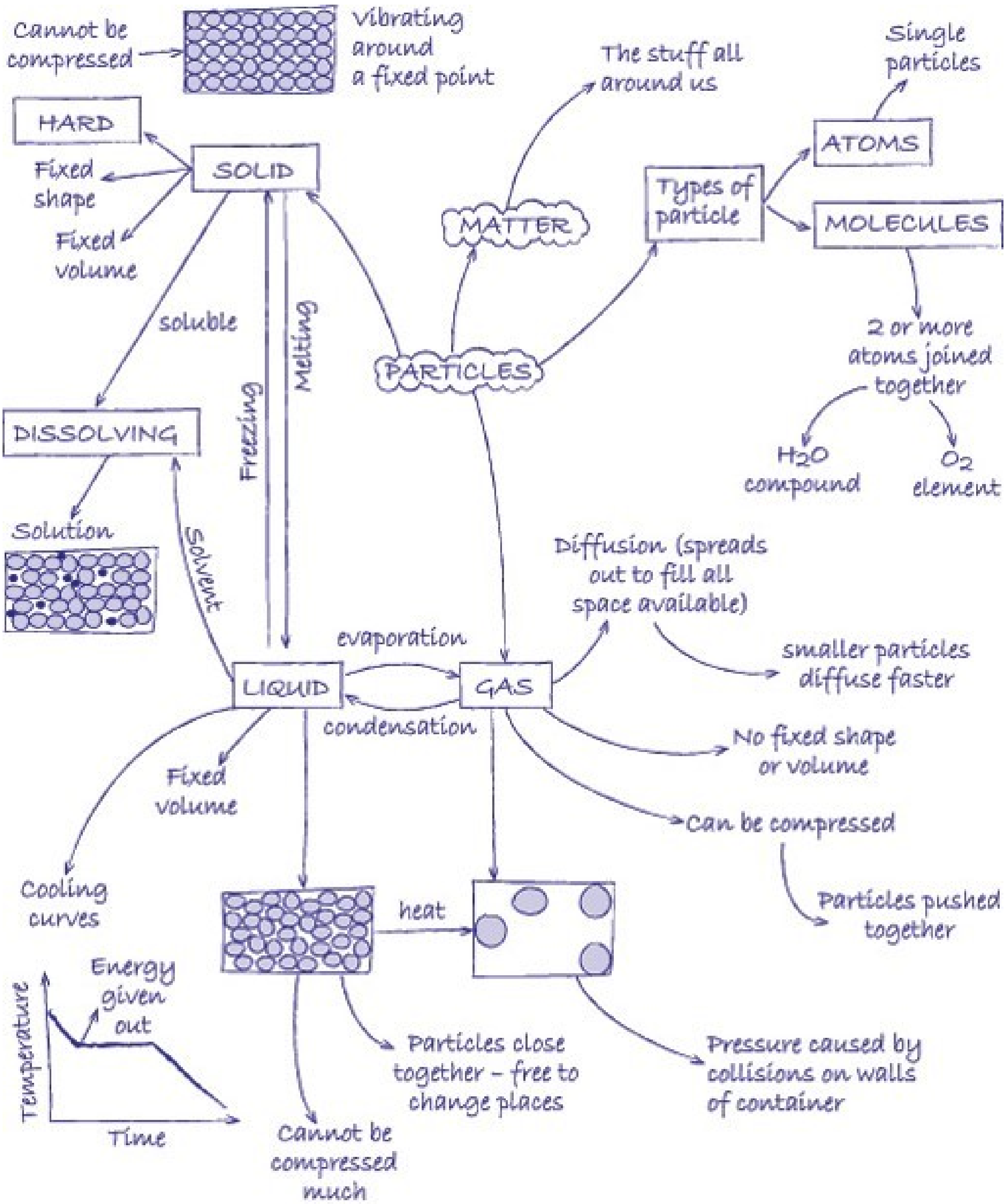

Diagram 2 Particles mind map

Resource 6: Corn starch and water

Background information / subject knowledge for teacher

Corn starch and water – a curious mixture!

Caution: Always dispose of the mixture in a rubbish bin. **Do not** put it down a sink as it will cause a blockage.

Your students will probably be familiar with the properties of solids, liquids and gases. They will be able to describe their properties and, classify a substance correctly on the basis of its properties. This is fine so long as a particular substance falls neatly into one or other of the categories. But what happens if it doesn't? You have seen, for example, that sand, though composed of tiny grains of solid behaves, in some ways, like a liquid. Only one individual grain on its own would satisfy all of the criteria for a solid.

So some substances are definitely difficult to classify. However, you can use this as an opportunity to probe your students' understanding of the nature of solids, liquids and gases. In this activity you will make a substance that is difficult to classify. The substance is made from water and cornstarch. In order to experiment with it you will need the following materials:

- One box of cornstarch, 450 g (16 oz), or equivalent (a powder with a high starch content)
- A large mixing bowl
- A jug of water
- A spoon
- A large plastic food bag
- Newspaper or similar to cover the floor
- Water
- Food colouring
- A cup or beaker

Method

- Pour approximately $^1/_4$ of the box (about 100 g, 4 oz) of cornstarch into the mixing bowl and slowly add about $^1/_2$ cup of water. Stir. Sometimes it is easier (and more fun) to mix the cornstarch and water with your bare hands.
- Continue adding cornstarch and water in small amounts until you get a mixture that has the consistency of honey. It may take a few tries to get the consistency just right, but you will eventually end up mixing one box of cornstarch with roughly 1 to 2 cups of water. As a general rule, you're looking for a mixture of approximately 10 parts of cornstarch to 1 part water. Notice that the mixture gets thicker or more viscous as you add more cornstarch.
- Sink your hand into the bowl of cornstarch and water, and notice its unusual consistency. Compare what it feels like to move your hand around slowly and then very quickly. You can't move your hand around very fast! In fact, the faster you thrash around, the more like a solid the mixture becomes. Sink your entire hand in and try to grab the fluid and pull it up. That's the sensation of sinking in quicksand.

- Drop a small object into the cornstarch mixture and then try to get it out. It's quite difficult to do.
- Slap the surface of the mixture hard. If you have used just the right proportions it will not splatter all over the place as you might have expected.

Explaining the properties of cornstarch 'quicksand'

Cornstarch mixed with water is an example of a **heterogeneous mixture**. That's a bit of a mouthful! Basically it means that both components of the mixture can be seen in the mixture, or they could be if the particles of cornstarch were not so small. Over time the particles settle out and sink to the bottom so do not pour any remaining mixture down a sink – the water will evaporate and leave a solid lump of matter that will block it.

In fact the cornstarch and water mixture acts like a solid sometimes and a liquid at other times. The mixture is in fact an example of a suspension – a mixture of two substances, one which is finely divided (the solid) dispersed in the other (the liquid).

When you slap the surface with your hand you force the long starch molecules closer together. It feels like a solid. This impact traps water molecules between the starch chains and forms a semi-rigid structure. When the pressure is released, the cornstarch flows again.

If you push your finger slowly into the mixture, it goes in easily and it feels like a liquid.

All fluids have a property known as *viscosity* – or resistance to flow. The more resistance to flow a liquid has the greater its viscosity is; e.g. honey,. Water has a low viscosity. Sir Isaac Newton proved that viscosity is affected by temperature. So, if you heat honey, its viscosity is less than that of cold honey. Cornstarch, water mixtures and quicksand are regarded as ***non-Newtonian*** fluids because their viscosities change when a force is applied, *not* when heat is applied.

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Secondary Subject Resources

Science

Module 3 Physics

ENGLISH

TESSA (Teacher Education in Sub-Saharan Africa) aims to improve the classroom practices of primary teachers and secondary science teachers in Africa through the provision of Open Educational Resources (OERs) to support teachers in developing student-centred, participatory approaches. The TESSA OERs provide teachers with a companion to the school textbook. They offer activities for teachers to try out in their classrooms with their students, together with case studies showing how other teachers have taught the topic, and linked resources to support teachers in developing their lesson plans and subject knowledge.

TESSA OERs have been collaboratively written by African and international authors to address the curriculum and contexts. They are available for online and print use (http://www.tessafrica.net). Secondary Science OER are available in English and have been versioned for Zambia, Kenya, Uganda and Tanzania. There are 15 units. Science teacher educators from Africa and the UK, identified five key pedagogical themes in science learning: probing children's' understanding, making science practical, making science relevant and real, creativity and problem solving, and teaching challenging ideas. Each theme is exemplified in one topic in each of Biology, Chemistry and Physics. Teachers and teacher educators are encouraged to adapt the activities for other topics within each subject area.

We welcome feedback from those who read and make use of these resources. The Creative Commons License enables users to adapt and localise the OERs further to meet local needs and contexts.

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Contents

Section 1 : Properties of matter

Theme: Probing students' understanding

Learning outcomes

By the end of this section, you will have:

- provided opportunities for students to develop understanding of the properties of matter through talking;
- planned questions at different ability levels in order to find out about your students' understanding of the properties of matter;
- used students' writing and drawings to probe their understanding of how particle theory explains the properties of solids, liquids and gases.

Introduction

At the end of teaching a topic, teachers usually set a test or an exam to find out what their students have learned. They are often dismayed to find that it is not as much as they expected but by this time it is too late to help students. A good teacher will find out what students understand as they go along and what the students are finding difficult and help them to make progress.

This unit has three short activities that will fit into your normal teaching about **properties of matter** and will show you how to find out what your students understand. Don't worry – the activities won't prevent you from finishing the syllabus; they are fairly short and will help your students to learn. Once you have tried these activities, you will be able to adapt them when you teach other topics.

1. Exploring students' prior knowledge

Students have their own ideas about a topic and an effective teacher takes account of these ideas when teaching. So a good way to start teaching any topic is to find out what your students already know about the topic. You may be surprised about what they have learnt from newspapers, adults, peers, older brothers and sisters and observations. Often their ideas are not the same as the scientific ideas we want them to understand. Why do you think that is the case?

At primary school, students may have learnt that matter can be divided into solids, liquids and gases. They will not necessarily remember all the details, but they will certainly not be 'empty vessels'. If teachers assume that they need to start from the beginning then students easily get bored and there is a danger that they will keep any misconceptions they have.

Activity 1 is designed to consolidate and extend their understanding and for you to develop your ability to probe understanding through questioning. It is important to make sure that your questions challenge your students. **Resource 1** reminds you about the different types of questions that you should be asking. It is a good idea to plan the questions that you could ask before the lesson. Think about how you might respond to their answers. You could ask several students the same question then ask the students to select the best one. You could also ask a follow-up question: 'Why do you think that?'

Resource 2 provides some background to the teaching activity described in **Case study 1**. The activities will help you to build on the knowledge and understanding that your students already have.

You start by revisiting ideas that they will have met in primary school, but then extend these to more substances, helping them to realise that lots of things around them are a mixture of a solid and a gas, or a solid and a liquid. For example, a sponge looks like a solid but doesn't have all the properties of a solid.

Case study 1: Investigating a new substance

Mr Yaya planned a fun activity for his class (see **Resource 2**). When he was at college one of the lecturers showed him that if you mix corn starch and water in certain quantities they make a very peculiar substance. He went to an internet café and found a film on YouTube of someone walking on custard (a mixture of corn starch and water). Mr Yaya divided his class into groups and gave them a bowl of corn starch which they had to mix with water. He gave them 10 minutes to play with it. He then gathered them round the front and started asking them questions. He started with closed, easy questions based on their observations. What colour is the mixture? Does it smell? Then he asked some more open-ended questions. What have you discovered? Do you think it is a solid or a liquid? Why do you think it is a solid or liquid? He let several different students answer the same question. He asked them about particles. He found that several children remembered how the particles are arranged in a solid, but a lot were confused by liquids. He drew diagrams on the board and gave them another chance to experiment with the mixture. While they were working he asked them questions to make them think about whether it was a solid or a liquid and how the particles might be arranged. Finally he gathered them round the front and asked one group to argue in favour of it being a liquid and one to argue for it being a solid.

The students had a lot of fun and by the end, Mr. Yaya was confident that they remembered the properties of solids and liquids and how the particles were arranged in each one.

Activity 1: Using questioning effectively

You will need to collect a set of objects or pictures of objects that represent solids, liquids and gases. Some of them will be obvious, some will be more difficult to classify as they will be a mixture of a solid and a gas (e.g. a sponge) or a liquid and a gas (e.g. a picture of a cloud, bottle of fizzy drink) and some will be unusual (e.g. jelly or plasticine). **Resource 3** has some suggestions. Before the lesson divide your objects (or pictures) into two groups – those that are obvious and those that are more complicated. Gather your class round the front. Ask easy closed questions that will help them remember the properties of solids, liquids and gases. Summarise the properties of solids, liquids and gases on the board. (You could ask one of the students to do this). If as a result of your questioning you find this is too easy for them, go straight on to the more difficult objects.

Good teachers will change their plan if necessary to stop the students getting bored. When you are confident that the properties of solids, liquids and gases are understood, introduce the second group of pictures or objects. Ask them to work in groups of four to discuss how the objects can be classified. Keep asking them why. Why can the sponge be compressed? Why does sand flow? Get each group to report back on one of the objects. Encourage the others to ask questions.

2. Using discussion to develop understanding

Talking about a problem is a good way to organise your thoughts and ideas. In **Activity 2** you will provide your students with the opportunity to discuss the answers to a set of questions with each other. Listening to their conversations will give you insights into their thinking and help you to work out how best to support them. It will also provide an opportunity for the students who understand the topic quite well to help those that don't. You should think about how to divide the class up. Will you let them work with their friends or will you organise the class so that they work with different people in mixed ability groups? **Activity 2** is designed to help your students understand the particle model for matter. You can also begin to get them to make the link between the properties of the material and the forces between the particles. The case study describes a different way of organising the same activity. In both cases the aim is to promote discussion.

Case study 2: Organising a 'card sort'

At a teacher education seminar, teachers worked together to plan practical, hands-on physics lessons that would help their students to understand the properties of materials. One of the student teachers, Mr Onsla, wrote cards with statements about particles (**Resource 4**). He then brought carton boxes into the classroom. He divided the class into groups of five, and asked each group to pick three boxes and to label each for the states of matter. On the side of each box the group then drew a diagram to show how the particles are arranged. Each student had three cards which they had to place in the correct box. The students had to explain why they placed a certain item in the specific box and the others could ask questions. The teacher noted that there were a lot of discussions among the students as they tried to make decisions.

Activity 2: Think-pair-share

Write the statements in **Resource 4** on the board and then follow the steps suggested. (Each statement should be numbered for ease of discussion at the end).

- Students should work on their own to match the number to solid, liquid or gas.
- Students compare their answers with a friend and make sure that they agree.
- Each pair shares their answers with another pair and they discuss the answers until they all agree.
- The groups of four compare their answers with another group and discuss until they agree.
- Finally, ask one representative from each group of eight to report on their answers. Wait for the students to point out any errors – don't do it yourself!

You can use this idea of think–pair–share with lots of different topics in science. It gives the students the opportunity to think for themselves, and it is a safe environment for them to make mistakes. They have to be able to justify their answers and students often find it easier to talk about their ideas than write them down. Talking also helps them to understand, and shows you what is going on in their mind.

3. Encouraging writing

One of the reasons why physics sometimes seems difficult is that we cannot see the things we are talking about. It is full of abstract ideas. You can help your students to understand ideas about physics by making the subject more concrete. You can do this through experiments and models. Giving your students the opportunity to write about their ideas is a very good way to find out what they understand. So getting them to write about an experiment in their own words can really help your students to understand and helps you to see what they do and don't understand. Resource 5 provides suggestions about how you might use writing to elicit understanding. In **Activity 3** you will carry out some demonstrations which your students will explain in their own words. You will provide some key words that you expect them to use and encourage them to use diagrams to explain their ideas. This will demonstrate how particle theory can be used to explain how solids, liquids and gases behave. **Case study 3** shows how a teacher uncovered a significant common misconception amongst his pupils and used this to change his lesson plan.

Case Study 3: Using role play to support understanding

Mr Molu asked his class to use the particle model to explain why liquids flow, why solids are hard and why gases can be compressed. He realised when he read what they had written, that there was a lot of confusion, particularly about the liquids and his students did not get very high marks. The students complained that everything in physics is abstract and difficult. He decided to try to motivate the class and make everything as concrete as possible. The previous day he had downloaded a simulation of how particles of solids, liquids and gases are arranged. In a double lesson he started by showing the class the simulation. Then he divided the class into three groups and asked them to role-play the simulations. Each student represented a particle: some students worked together to act being a solid. Others acted being a liquid and or being a gas. They were to report to the entire class how it felt to be solid, liquid and gas. Mr Molu posed the following questions:

- How close are particles in each case?
- How did the particles move in each case?

After this each group discussed and drew the arrangements, which they later redrew on the chalk board. The class was very lively and the students said that for once they experienced joy from being in a physics class.

Activity 3: Effective demonstrations

In this activity you will do some demonstrations that illustrate some of the properties of materials and get the students to explain the demonstrations in their own words. You should write some of the key words on the board. The demonstrations will depend on the equipment that you have, but could include the expansion of a solid when it is heated (ball and ring), the expansion of a liquid when it is heated (coloured liquid in a glass bottle), a needle floating on water, potassium permanganate dissolving in water.

The important thing is to give the students the chance to explain the ideas themselves. Resource 6 gives you some ideas. Use the demonstration to practise your questioning. Start by asking simple closed questions designed to make your students observe carefully and then get them to try and explain their ideas. By giving them the chance to explain the demonstrations in their own words, you will really be able to see if they understand.

Resource 1: Questioning

Teacher resource to support teaching approaches

Questioning

Good questioning is really important and is not as simple as it first may seem. It can help you develop good relationships with your students, it can help your students to organise their thoughts and therefore help them to learn, and it can provide you with valuable insights into their thinking. Good questions can promote thought, encourage enquiry and help with assessment.

By thinking carefully about the sorts of questions that you can ask, you will improve your teaching.

It is helpful to think of questions as being ‘open’ or ‘closed’ and ‘person’ or ‘subject-centred’.

Closed questions have a single correct answer. They can reassure students and help you to find out what they remember. But too many closed questions can limit the opportunities to explore thinking and develop understanding. They are often undemanding and can be quite threatening if the student lacks confidence.

Open questions have no right answer, or several right answers. They give you opportunity to find out what your students are thinking, and can be less threatening for some students.

Subject-centred questions ask things like ‘what goes into a plant?’ and ‘what sort of rock is this?’

Person-centred questions focus on the student and are less threatening and more learner-friendly: ‘What do you think goes into the plant?’ ‘What do you notice about the rock?’

A committee of educators chaired by Benjamin Bloom devised a taxonomy of types of questions in which they identified ‘**lower order questions’** and ‘**higher order questions’**. Research shows that lower order, recall-type questions tend to dominate classrooms. This leads to an emphasis on remembering facts and reduces the opportunities for creativity, thinking and developing understanding (see table).

It is important that you **plan** your questions appropriately. When you are doing a practical demonstration, for example, or introducing a new topic, write out a list that includes some lower order and some higher order questions. This way, you will be using questions to help your students to learn. Just like every aspect of teaching, you need to practise! You also need to think about how you respond to your students’ answers. Try and give them time to think, ask several students the same question or let them discuss the answer before they respond.

Conventionally, students are asked to put their hands up when they answer a question. You probably find that the same students frequently put their hands up and some do so very rarely. It can be very effective to ask specific students to answer your questions and **not** to ask them to put their hands up. Everyone will have to listen as they know that they might get asked. When you first start doing this, make sure that you direct easy questions at students who you know will find the work difficult. If they can successfully answer some of your questions, they will become more confident.

Bloom's taxonomy of questions

Type of questions	Purpose	Examples
Lower order questions		
Recall	To see what your students remember	Who is? What are? Where are? When did?
Comprehension	To see if your students understand what they can remember	Explain why? What are the differences between? What is meant by?
Application	To see if your students can use their knowledge	How would you classify these invertebrates? What is the evidence that this is a metal?
Higher order questions		
Analysis	To help your students think critically To see if they can make deductions and draw conclusions	Why? What do you think will happen if? What do your results show? What would be the effect on?
Synthesis	To help your students create new ideas from existing information	What would happen if there was no friction? Suppose the Earth rotated at half the speed?
Evaluation	To encourage your students to form opinions and make judgments	How effective is? Which is best and why? What do you think?

Adapted from Amos, S. (2002) 'Teachers' questions in the classroom' in Amos, S., Boohan, R. (eds) *Aspects of Teaching Secondary Science*, London, RoutledgeFalmer.

Resource 2: Corn starch and water

Background information / subject knowledge for teacher

Corn starch and water – a curious mixture!

Caution: Always dispose of the mixture in a rubbish bin. **Do not** put it down a sink as it will cause a blockage.

Your students will probably be familiar with the properties of solids, liquids and gases. They will be able to describe their properties and, classify a substance correctly on the basis of its properties. This is fine so long as a particular substance falls neatly into one or other of the categories. But what happens if it doesn't? You have seen, for example, that sand, though composed of tiny grains of solid behaves, in some ways, like a liquid. Only one individual grain on its own would satisfy all of the criteria for a solid.

So some substances are definitely difficult to classify. However, you can use this as an opportunity to probe your students' understanding of the nature of solids, liquids and gases. In this activity you will make a substance that is difficult to classify. The substance is made from water and cornstarch. In order to experiment with it you will need the following materials:

- One box of cornstarch, 450 g (16 oz), or equivalent (a powder with a high starch content)
- A large mixing bowl
- A jug of water
- A spoon
- A large plastic food bag
- Newspaper or similar to cover the floor
- Water
- Food colouring
- A cup or beaker

Method

- Pour approximately $^{1}/_{4}$ of the box (about 100 g, 4 oz) of cornstarch into the mixing bowl and slowly add about $^{1}/_{2}$ cup of water. Stir. Sometimes it is easier (and more fun) to mix the cornstarch and water with your bare hands.
- Continue adding cornstarch and water in small amounts until you get a mixture that has the consistency of honey. It may take a few tries to get the consistency just right, but you will eventually end up mixing one box of cornstarch with roughly 1 to 2 cups of water. As a general rule, you're looking for a mixture of approximately 10 parts of cornstarch to 1 part water. Notice that the mixture gets thicker or more viscous as you add more cornstarch.
- Sink your hand into the bowl of cornstarch and water, and notice its unusual consistency. Compare what it feels like to move your hand around slowly and then very quickly. You can't move your hand around very fast! In fact, the faster you thrash around, the more like a solid the mixture becomes. Sink your entire hand in and try to grab the fluid and pull it up. That's the sensation of sinking in quicksand.

- Drop a small object into the cornstarch mixture and then try to get it out. It's quite difficult to do.
- Slap the surface of the mixture hard. If you have used just the right proportions it will not splatter all over the place as you might have expected.

Explaining the properties of cornstarch 'quicksand'

Cornstarch mixed with water is an example of a **heterogeneous mixture**. That's a bit of a mouthful! Basically it means that both components of the mixture can be seen in the mixture, or they could be if the particles of cornstarch were not so small. Over time the particles settle out and sink to the bottom so do not pour any remaining mixture down a sink – the water will evaporate and leave a solid lump of matter that will block it.

In fact the cornstarch and water mixture acts like a solid sometimes and a liquid at other times. The mixture is in fact an example of a suspension – a mixture of two substances, one which is finely divided (the solid) dispersed in the other (the liquid).

When you slap the surface with your hand you force the long starch molecules closer together. It feels like a solid. This impact traps water molecules between the starch chains and forms a semi-rigid structure. When the pressure is released, the cornstarch flows again.

If you push your finger slowly into the mixture, it goes in easily and it feels like a liquid.

All fluids have a property known as *viscosity* – or resistance to flow. The more resistance to flow a liquid has the greater its viscosity is; e.g. honey,. Water has a low viscosity. Sir Isaac Newton proved that viscosity is affected by temperature. So, if you heat honey, its viscosity is less than that of cold honey. Cornstarch, water mixtures and quicksand are regarded as ***non-Newtonian*** fluids because their viscosities change when a force is applied, *not* when heat is applied.

Resource 3: Background information on states of matter

Background information / subject knowledge for teacher

Basic properties of matter

A solid	A liquid	A gas
• has a definite shape and a fixed volume • is very hard to compress.	• takes the shape of the container and has a fixed volume • is hard to compress • flows.	• has no 'shape' and no fixed volume. • will spread throughout any container or space available • is easy to compress and can be compressed easily.

Some examples of materials that are harder to classify

Some materials appear to be a single substance but aren't:

- Sand (or powders, like flour). This flows (like a liquid) but is made of tiny bits of solid. There is air in the gaps between the sand particles.
- Modelling clay (e.g. 'plasticine') is a mixture of a solid and a liquid. It loses its oil as it gets older, and becomes, dry, hard and unworkable.
- A cloud floats in the air (like a gas) but is composed of many tiny droplets of water in air.
- A jelly is a mixture in which small amounts of a liquid are mixed into another material which is a solid.
- Toothpaste is a mixture in which there are small amounts of a solid mixed in amongst another material which is a liquid.
- A foam is a mixture in which there is a gas mixed into another material which is a liquid.
- A sponge is a solid with air or liquid mixed with it. As a result it can be compressed, unlike most solids.
- Some liquids (like tomato ketchup) are thick and do not flow very well, but if you shake them, they become thinner and flow easily.

Resource 4: Card sort activity

Teacher resource for planning or adapting to use with pupils

Set of statements about solids, liquids and gases

1. Particles are held together by a strong force.	2. Particles are moving freely in all directions.	3. Particles are slipping past each other.
4. Particles are not in an orderly structure, but are held very close together.	5. Particles keep to a particular place in an orderly structure.	6. The particles are spread out. Each particle moves in a straight line until it collides with another particle.
7. Particles can only vibrate.	8. Particles are constantly colliding with each other and changing position.	9. Particles are in constant, rapid movement.
10. Heating the substance makes the particles move around faster and collide more often.	11. Heating the substance makes the particles vibrate more vigorously.	12. Heating the substance makes the particles move around faster.
13. Collisions make particles change speed and direction.	14. Occasionally, one particle on the edge of a group will be knocked so hard it escapes from the group.	15. Some particles are moving much more slowly than most, some are moving much more quickly.

Answers for teachers

Solid: 1, 5, 7, 11

Liquid: 3, 4, 8, 10, 14, 15

Gas: 2, 6, 9, 12, 13, 15

Resource 5: Students’ writing

Teacher resource to support teaching approaches

Students’ writing

Getting students to write about their ideas is a good way to find out what they understand. Traditionally most of the writing that students do in science involves writing short answers to closed questions, or copying notes from the board. If this is all the writing that your students do, then you will be missing opportunities for them to demonstrate what they know and to be creative.

Writing in science should definitely not be restricted to answering questions and copying notes. There are a variety of ways in which you can use children’s writing to probe their understanding, develop their knowledge, motivate them and refine their skills. Some of these are summarised below.

DARTS

This stands for **Directed Activities Related** to **Texts**. As the name suggests the activities involve pupils working with texts that have been changed in some way. These activities provide a good alternative to simply copying off the board as the students will have to think about what they are writing.

One common approach is to provide some text with words missing. The students have to fill in the gaps. The missing words can be listed below, or not, depending on the abilities of the pupils. The first letter of the missing words can be supplied, which makes it a bit easier.

Other approaches are as follows:

- Sentences that link together to explain a process or phenomenon can be jumbled up and pupils have to decide their correct order.
- Sentences that have to be completed in order to provide complete definitions.
- Diagrams are provided which students have to label.
- A table is provided with some gaps to be filled in.
- A piece of text is provided in which students have to underline key words or definitions.
- A piece of text is provided and students have to use it to make a table or a diagram or produce a summary.

Word matching

You supply a list of scientific words, and definitions. Students have to match the right word with the correct definition.

Experiment write up

Encouraging your students to write about their experiments in their own words will show you how much they understand. A strategy that teachers often use is to provide some headings and some key words that their students should be trying to use so that they can structure their writing.

Concept map or mind map construction

This involves breaking down a complex idea, or process, into sections and linking them graphically to display their logical sequential relationships and how they contribute to an understanding of the whole. This is normally quite difficult and needs a lot of practice. Probably more significantly it requires a sound knowledge of the subject if the maps are to make sense.

Writing for different audiences

This sort of writing sometimes helps students who find science difficult, but who enjoy humanities. Examples include:

- Producing a poster. This will not only give pupils an opportunity to demonstrate their knowledge and understanding in writing but also enable them to use drawings and diagrams to illustrate science concepts.
- Producing an information leaflet on a particular topic that could be used by younger children.
- Writing a letter or a newspaper article to express a point of view. For example, arguing for an issue which involves explaining some scientific background such as vaccination, or preventing HIV.

Resource 6: Ideas for demonstrations

Background information / subject knowledge for teacher

Expansion of a solid: ball and ring

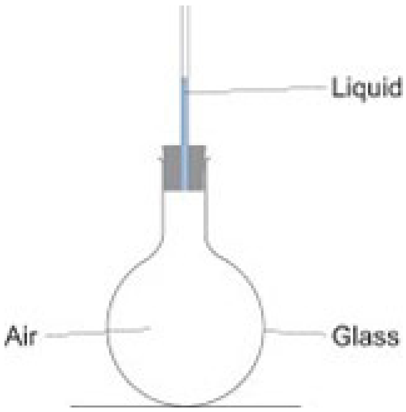
When both the ball and ring are at room temperature, the ball can be dropped through the ring. Heating the ball makes the metal expand, so it cannot pass through the ring. As the ball cools down, it contracts and will fit through the ring again.

Key words: solid, heating, cooling, expansion, expand, contraction, contracts particles, vibration, vibrate, energy

Expansion of a liquid: model thermometer

Fill a boiling tube with coloured water, then insert a narrow glass tube (inserted through a cork or bung) into the neck of the boiling tube: make sure the end of the glass tube is in the water. As you heat the water in the boiling tube, you should see the column of coloured liquid in the glass tubing get higher and higher, because the liquid is expanding as it is heated. This is how liquid-in-glass thermometers work.

Key words: liquid, heat expansion, expands, particles, movement, energy



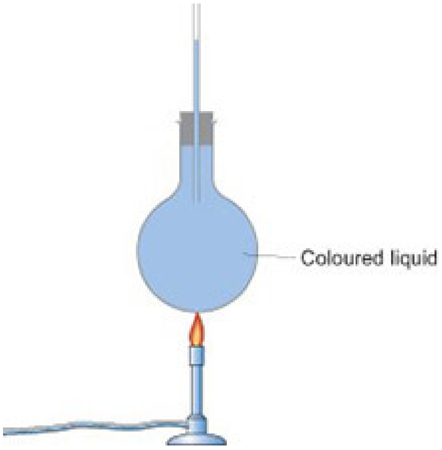
Expansion of a gas: liquid in a tube/bubbling flasks

You can show this by using a test tube or boiling tube with a piece of capillary tubing inserted into it through a bung. The capillary tubing should have a very small amount of water in it. If you warm the tube with your hands, you should see the water rise up the tube: it is being pushed up by the air which is trapped inside the test tube.

Another way to do this is to use a boiling tube or round bottomed flask with a narrow glass tube inserted into it. Clamp the tube or flask so that the open end of the glass tubing is below the surface of a trough of water. When you warm the air in the flask with your hands, bubbles of air will come out of the tubing into the water.

You can demonstrate the opposite process – contraction of a gas as it cools – if you have an empty plastic drinks bottle with a screw top. Pour some hot water into the bottle, swirl it round, then pour it out again. Screw the top back on straight away. Leave the bottle to cool down and watch as it collapses (because the cooling air inside contracts).

Key words: gas, heating expansion, expands, contracts, contraction, particles, collisions, energy



Dissolving and diffusion

Potassium permanganate crystals in water

Get a glass trough, or a large glass beaker or glass bowl and put water in it to about 10 cm depth. The container must be on a steady surface, and give a good view of the contents either from the side or from above. It helps to have some white paper under the container and behind it, so it will be easier to see any colour changes in the water. Let the water settle completely, then drop one or two (no more) potassium permanganate crystals into the water. The colour spreads out slowly from the crystal and the crystal gets smaller as it dissolves in the water. Purple colour is evidence that there is some potassium permanganate in that bit of the water. If left long enough, the purple colour will spread throughout all of the liquid and the colour will be the same intensity, instead of being deepest near the crystal. The slow colour spreading is evidence of diffusion.

Key words: potassium permanganate crystal, solid, dissolving, dissolves, diffusion, particles, collisions, random

Perfume in air

Spray some strong perfume in one corner of the room. Ask your students to put their hand up when they can smell the perfume. The perfume particles will diffuse through the room, with the people nearest to where it was sprayed, smelling it first. Comparison with the potassium permanganate experiment shows that diffusion is faster in gases than in liquids.

Key words: diffusion, particles, collisions, spaces, random

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Section 2: Measurement

Theme: Making science practical

Learning outcomes

By the end of this section, you will have:

- organised students in small groups to use apparatus to solve a problem;
- designed questions at different levels to enable students to participate in a practical demonstration;
- organised children into groups to collect data and present it appropriately.

Introduction

Organising practical work is an important part of being a science teacher. Gaining first hand experience of materials, organisms and processes can increase understanding and assist retention of knowledge. Shared experiences and real objects may also be helpful for students who find English difficult. All practical work requires careful planning and some improvisation.

In this unit we take the topic of measurement and illustrate three different ways of organising practical work: demonstration, a laboratory parade and solving a problem. Some of the ideas in this topic are demanding and in your class you will find that some students race ahead, whereas others find the ideas difficult. We have used these activities to show how you can differentiate the work and cater for students of all abilities. You need to be able to support those who are finding the work difficult and challenge those who are capable of taking it further. **Resource 1** provides some ideas about the different ways of differentiating work.

1. Thinking about measurement in groups

Practical work has many purposes. It might be to learn a particular skill, or to help motivation and enjoyment. It can also be used to promote higher-order thinking skills and to encourage students to talk about science and communicate their ideas in a variety of ways. **Resource 2** contains some general information about organising practical work. In the first activity, you will use the apparatus as a stimulus to promote thinking and talking. There is an opportunity for you to question students in groups while they are working and for you to target your questions at a level suitable for that group.

Case study 1: How will you organise groups?

Mrs Egwali gathered the basic instruments that were available in the school lab. She also borrowed some micrometer screw gauges from a neighbouring school. Previously she had asked the students to bring any measuring instrument that they could get from home and something that could be measured with their instrument. They bought things like tape measures, measuring jugs and simple scales. Mrs Egwali put the measuring instruments and some objects to be measured on the table. She also cut cards from manila paper and placed them on the table. She divided the students into groups of five. Each group had to work as fast as possible and follow a set of instructions:

- Pick one instrument and discuss its correct name among the group.
- Write the name on the card.
- Pick up the object it can measure accurately and write its name on the card.
- Place the cards next to the instrument and what it measures.

Mrs Egwali walked around while the students worked. They were actively involved except for two groups in which some students were quite passive. She reorganised the two groups and put the passive students together. It pleased her to note that when they were put together they became more involved. She realised that this was because their abilities were similar and they felt more confident. Before the lesson ended, she noted that no group had picked the micrometer. She demonstrated to them how it works and this led to a discussion about which instruments were the most accurate. Joshua had bought a spoon and a bag of sugar. Mary said that that wasn't a very accurate way of measuring but Joshua said his mother's cake was always perfect! Mrs Egwali explained that in science it was important to make accurate measurements. Some of the instruments had been given various names, so she asked students to choose the correct one.

Activity 1: Getting started with measurement

Before the activity gather as many pieces of measuring equipment as you can at the front of the class. Gather the students round the table and ask them to name as many pieces of equipment as they can.

Divide the class into groups and ask each group to work out what they think the instruments might be used for. (**Resource 3** has some ideas of equipment you could use and questions you could ask while they are working.)

Ask the groups to report back. While they are working go round and ask some leading questions to help the students to work out the uses. If you have something like a micrometer, see if they can work out how to use it before you explain to them. Get them to think about when it might be used.

Ask each group to measure the length of an exercise book to the nearest millimeter. Collect all the measurements on the board. You will find some variation! Look at the list. Are there any readings you could reject as they are clearly inaccurate? What is the average? What is the range? Use these results to explain that it is important for scientists to measure things carefully.

After the activity, reflect on how you divided up the students. Did each group have questions of an appropriate level? Was it easy to decide who to put in what group? Do you always let them work with their friends?

2. Organising a 'circus' of experiments

Organising a laboratory parade (or circus of experiments) is a good way to enable students to perform their own experiments when you only have one set of apparatus. By devising a set of activities which are related, students move from station to station and gradually build up their understanding. Again, the students will be working in groups. You will need to decide how to organise the groups. You are also encouraged to think about ways of challenging the students who have a good understanding of the work.

By getting each group to measure the same objects and record their results on the board, you will be able to explain the concepts of 'accuracy' and 'precision'. There is also an opportunity to calculate averages. **Case study 2** describes a situation in which the teacher does not have very much equipment. **Activity 2** shows what you can do with more equipment and **Resource 4** gives you some specific ideas.

Case study 2: Making measurements

Mrs Otieno has limited access to measuring instruments and teaches in a mixed school. She had noticed that whenever they worked together the boys tended to do the work while the girls watched. She organised three stations for measuring the diameter of a pipe, the mass of small stones the students had brought from a nearby river and the volume of the same stones. With work stations for each measurement, she divided the class into groups of boys and girls. At the same time she had drawn a table on the board with a column for readings of volume, diameter and mass. She had three beam balances, three eureka cans, three measuring cylinders and three vernier calipers. Each group was asked to measure and record the value on the appropriate column on the board, within 5 minutes, and then move to the next station. In a previous lesson she had demonstrated how the vernier calipers, beam balance and measuring cylinder worked. The students enjoyed handling the apparatus, especially the girls who filled in their results before the boys. She also noted with a lot of pleasure how creative the students were in using the eureka can. There were variations in the readings. Mrs Otieno used this to help her students understand the idea of 'uncertainty' and the importance of using averages. She asked them to calculate the average for each of the three readings.

Activity 2: Thinking about 'uncertainity'

Set up some different activity stations around the room. There are some suggestions in **Resource 4** , but you may need to use different ones, depending on the equipment that you have available. Divide your class into groups and give them 4 or 5 minutes at each station. (Use a stop watch to time it.) While they are working, make a table on the board with a column for each station and ask one person from each group to write their measurements in the correct column. Emphasise that they should write their answer, even if it is different from the others. At the end gather them round the front and ask them to think about why some of the answers might be different. You could get them to calculate some averages and explain the difference between precision and accuracy. For the activities that used imprecise equipment (e.g. kitchen measuring jug) you could ask them to name a more accurate piece of equipment for doing the same job.

3. Solving measurement problems

Much of the practical work that goes on in schools and universities involves students following detailed instructions. In some contexts, this is very important but it can lead to students losing sight of why they are being asked to do a particular thing. It is good for students to have the opportunity to design their own experiments. In **Activity 3** they have to design an experiment to solve a particular problem. There will be more than one solution. This would be an opportunity to divide your students into mixed ability groups. The students who find the work quite easy will be able to help those who find it more difficult and in doing so will consolidate their own understanding. In **Case study 3** the teacher uses some amazing facts to motivate her students and gets them to do some estimating so they can get a 'feel' for different masses and lengths.

Case study 3: Estimating size

Mrs Nakintu went to an internet café and looked up some interesting facts about the Earth – she found the mass of the Earth and its circumference, the length and breadth of their country, the distance to the moon, the distance to the sun (see **Resource 5**). She started the lesson by putting her students in groups and asking them to guess the answers to the questions. To make it a bit easier she wrote three possible answers on the board for each question and they had to select the correct one. The idea was to help her students understand the range of measurements that can be made and to get them interested

She then gave them some everyday objects and asked them to guess the mass or the length. She also asked them to estimate the size of the room. Each group wrote their answers on a piece of paper and handed it in.

She gave the pieces of paper out (so each group had answers by a different group) and asked different students to make the measurements. She wrote the answers on the board and the groups marked each other's work – 3 marks if they were within 10%, 2 marks if they were within 50% and 1 mark if they got the right order of magnitude. It did not take very long and the class enjoyed themselves.

Activity 3: Solving problems

This is a problem-solving exercise. Divide the class into eight groups. Choose four problems, so that pairs of groups are given the same problem. The problems involve using a combination of instruments or creative thinking to make a measurement that cannot be made directly.

Suggested problems could be finding the height of a tree, finding the volume of a stone, finding the mass of one sheet of paper, finding the area of the palm of your hand, finding the thickness of one piece of paper, finding the mass of a grain of rice, finding the pressure exerted by a student on the ground.

Students compare what they did and the answer they got with the other group and evaluate their own work. Groups who solve their problem easily can be given another one to do.

Resource 1: Differentiating work

Background information / subject knowledge for teacher

Differentiating work for students of varying abilities

As you will, of course, understand, each pupil has different abilities. There can also be a significant difference in age between the oldest and youngest pupil in the class. Some students will learn more effectively by reading a book, some by carrying out a practical activity and some by listening to and absorbing spoken instructions. Some will understand the work very easily, some will take more time. Some will work very quickly through any task you set, some will work slowly. It is impossible for you as a teacher to take all the differences into account all the time, but there are things that you can do to support individuals within a class.

If you have a class of 30 or more pupils this might sound like a daunting task! There are two important things that you need to do to be able to effectively cater for everyone in your class:

1. **Know your students.** You need to give them opportunities to work in groups and listen to the conversations; you need to mark their written work; you need to ask questions of individuals in class and you need to encourage them to ask you questions if they don't understand or just want to know more. When you know who understands easily, who finds science difficult, who likes to talk, who likes to write, who likes to draw and who likes doing experiments, you will be in a much better position to help individuals.
2. **Know your subject.** It is unrealistic to expect everyone to remember and understand everything that you do. Students who find science difficult will be overwhelmed if you try and tell them everything. You need to break each topic down into simple steps and make sure that everyone understands the most important ideas.

You can cater for the range of abilities within your group in two main ways:

Differentiating by outcome

This can involve providing a set of questions that get progressively more difficult. Everyone gets as far as they can. Alternatively, you can set open-ended tasks in which students demonstrate what they can do. This also gives you the opportunity to give them a choice about how they present their work, which can be very motivating. You may find that the degree of support that you need to provide to individuals, pairs or small groups within the class varies significantly.

Differentiation by task

This involves setting different students, or groups of students different tasks. For example, in a practical session some pupils could have instructions provided for them in written form and some could have them in diagram form and some could have a combination of both.

You could provide a set of questions that cover the basic ideas that you judge that everyone needs to understand and a set that are more challenging. The students who you expect to get a grade A could be given the more challenging ones.

Learning style

There is a lot of research that suggests that different students prefer to learn in different ways. The three learning styles that are more commonly referred to are visual, audio and kinaesthetic, i.e. some students prefer diagrams and pictures, some learn best by listening and some prefer to be able to do things.

As a teacher you cannot be expected to cater for all the students all the time, but a good teacher will make sure that their lessons contain activities that cover all three learning styles.

There is a tendency to expect students to do a lot of listening. You should make sure that your students also get to do experiments or activities that involve moving around the room and talking about the science. Encourage them to use mind-maps and diagrams or pictures to summarise key ideas, rather than simply copying not

Resource 2: Practical work

Teacher resource to support teaching approaches

Practical work

Introduction

Practical work is an important part of learning about science and learning to be a scientist.

The TESSA materials consider practical work in science involves pupils finding out, learning and verifying through observation and experiment, using skills and methods that are used by scientists in the real world. There are different types of practical work, which serve different purposes. Over time, a good teacher will make sure that their students experience different types of practical work.

Purposes of practical work

Different types of practical work and particular experiments will meet different objectives, but the benefits of practical work include:

- Developing practical skills and techniques such as how to use a microscope.
- Gaining first hand experience of materials and processes that may increase their understanding of science and help the retention of knowledge.
- Developing inquiry skills, such as control of variables, analysis and recording of data and looking for patterns.
- Motivation and enjoyment.
- Encouraging and promoting higher levels of thinking. Pupils can be asked to predict and explain when presented with problems and phenomena.
- Communication skills. Practical work may provide a context for the development of communication skills. The link to shared experiences and real objects may be very helpful for learners with limited proficiency in English.

Types of practical work

- **Demonstrations** – A teacher may decide to do a demonstration for reasons of safety or due to lack of time or resources. They may also be the most suitable method for consolidating understanding or providing challenge. Try to actively involve pupils through questioning or through participating in conducting the experiment or activities before or during the demonstration (e.g. predicting if statements are true or false and then using observations to confirm or change their decision).
- **Structured practical –** Pupils do an experiment in groups. The teacher may give them instructions to follow, advice on recording and analysis and questions to help them relate their observations to theory. These may be suitable for practising skills and techniques, supporting particular inquiry skills, and gaining experiences.
- **Rotating (circus) practical** – Pupils in groups move from one experiment to the next at ‘stations’ in the classroom. The experiments should be related and instructions should be brief. Similar questions at each experiment will help pupils

gradually build their understanding of a key concept, e.g. particle theory of matter or adaptation. Some of the stations may include a card sort or problem to solve rather than an experiment.
- **Investigation** –Pupils plan, carry out and analyse their own experiment. They may have freedom to choose what they investigate or the teacher may limit the materials available or specify a topic to investigate. The teacher has a role as a facilitator rather than teacher. They will usually give pupils guidance on 'the scientific method' or carrying out a 'fair test'.
- **Problem solving** – this is similar to an investigation, but pupils have more freedom of approach. It may be a practical problem, such as dropping an egg from the top of a building without breaking it, which can be solved in a number of ways. This can be motivating and a good vehicle for the promotion of communication skills.

Organising practical work

Whenever you are planning an experiment, you should try it out yourself before the lesson. Simple experiments are often more complicated than you might think. You will also need to do a risk assessment. This means thinking about the potential hazards and taking steps to reduce them.

When dealing with chemicals other than water, students should wear safety goggles. If safety goggles are not available, you need to use very dilute solutions (0.1 M). The chemical that is most likely to cause permanent eye damage is sodium hydroxide (above a concentration of 0.4 M).

You will need to think about how your students will get the apparatus they need. The things you might consider could include:

- Give them an activity to do at their desks and, while they are doing it, you distribute the apparatus they will need.
- Spread out the different items around the room and ask one person from each group to collect what they need. By spreading it out, you will avoid the potentially dangerous situation of lots of people gathering in the same place.
- Give out the chemicals yourself with a teaspoon on to small pieces of paper that they can take back to their place. This will ensure that they get the right amount and will avoid a lot of mess!

Resource 3: Questions to ask about measurement

Teacher resource for planning or adapting to use with pupils

Examples of measuring equipment and questions

Here are some general ‘prompt’ questions you could ask pupils about pieces of equipment they don’t recognise:

- Can you see any unit names on it? Or maybe just a letter? What does it stand for? What do we use that to measure?
- Does it look like something you could make electrical measurements with? Could you connect electrical equipment to it?
- Are there any knobs you can turn? What happens when you do that?

You could make this easier for students if you make a table of quantities, units and abbreviations for pupils to refer to, here is an example:

Quantity being measured	Units it is measured in	Abbreviation
Current	amps (amperes)	A
Mass	kilos (kilograms)	kg
Force	newtons	N

Another way you could make the task easier is to use a small number of practical examples to make the identification process into more of matching exercise.

For example, if you had, an ammeter, a micrometer and a set of scales, you might provide a piece of leather or plastic, a circuit with a battery and a lamp, and a small object made of wood or metal, you might ask:

Which of these could I use to measure

- the thickness of this piece of plastic?
- the mass of this piece of metal?
- the current flowing through this lamp?

Here are some examples of specific pieces of equipment and questions you could ask about them:

- **Micrometer** – What things change when you turn the knob? (Hint: look at the scale, and look at what else is moving.)
- **Ammeter** (or voltmeter) next to a circuit with a lamp and a switch connected to a battery pack – What might you use this to measure?
- **Force meter** – What can you move on this? How do you move it? What do you think it might measure? What units is it marked in/ what letter(s) can you see on the scale? What does it (do they) stand for?
- **Voltmeter** (connected across a lamp which is connected to a battery pack by a switch) – What changes when you close the switch? What is this measuring?

- **Top-pan balance** or **kitchen scales** (with an analogue scale) – How can you get this to change the value next to the pointer? What units is it marked in? What do you think it measures?
- **Measuring cylinder** or **measuring jug** – How can you use this as accurately as possible (read it at eye level)? Which would be most suitable for measuring 10 ml and why?

Resource 4: Measurement 'circus'

Teacher resource for planning or adapting to use with pupils

Examples of stations for Activity 2

Note: If you have a camera (or a mobile phone with a camera) it would be useful to take photos of pupils as they carry out some of the activities. Look out for really good technique to praise, such as reading a measuring cylinder at eye level, but also try to catch some of the variations in how different people interpret an activity (e.g. Station 6 extension or dragging the load in Station 7).

Station 1

Equipment and notes
Circuit set up with three bulbs connected in series (with a switch in series) to a low voltage dc supply or battery pack providing about 4 V. The voltmeter should be correctly connected across the three lamps using two leads, but the switch to control the supply to the circuit should be left open for students to close themselves.

Instructions for pupils
Close the switch and record the reading in volts.

Station 2

Equipment and notes
Top pan balance or kitchen scales;

Mystery object such as a 20 g mass, or a pebble, in a box or bag (so that pupils won't see what it is and guess the answer).

Instructions for pupils
Place the bag (box) on the scales and record the mass.

Stations 3, 4 and 5

Equipment and notes
Stations 3 and 4 need identical small blocks of wood, about 2 cm thickness, but provide a ruler for Station 3 and provide a micrometer for Station 4;

Station 5 needs a small piece of sponge about 1 cm thick, plus either a ruler or a micrometer. All three stations need a small diagram to show which dimension pupils should be measuring.

Instructions for pupils
Measure the thickness of the object.

Station 6

Equipment and notes
Measuring cylinder or measuring jug with some water in it. Check that the water level hasn't been changed after each group. Provide a cloth for mopping up any spillages.

Extension 1: A second measuring cylinder and a pebble to measure the volume of. Students could either lower the pebble into the measuring container and note the change in volume, or use the measuring equipment to collect and measure the water which runs off from a displacement can.

Extension 2: A third measuring cylinder and a collection of 10 small stones (pebbles/gravel/shingle, all roughly the same size and each less than 1 cm across). For this, students will need to adapt the method used for Extension 1. One stone alone will not displace much water, but, students could find the volume displaced by 10 and then use that value to get an average for 1 stone.

Instructions for pupils
How much water is in the container? Record the volume of water in the container.

Extension1: Find the volume of the pebble. (Hint – the pebble displaces its own volume of water).

Extension 2: You have 10 tiny stones. Find the volume of 1 stone.

Station 7

Equipment and notes
2 x Force meters (spring balance): one of them (A) should be hanging from a stand, ready to attach the load, the other (B) should be left on the bench;

A small heavy object to attach to the spring balances.

Watch out for students 'dropping' the load onto the hook so that it falls off or bounces.

Make sure that both force meters are correctly zeroed at the start of the session. You add another aspect to the discussion by using a third force meter (C), set up like the first one but with the screw adjusted so that the 'zero reading' isn't zero. Check every so often that no-one has corrected it.

Instructions for pupils
Attach the object to the hook on the force meter which is hanging up. What is the weight of the object in newtons? (Take care: support the load as you hook it on, then move your hand away.)

Now take the load off and hook it onto the other force meter so that the load is resting on the bench. How much force does it need to drag the load *slowly and steadily* along the bench?

Answers and things to discuss with your students

These stations not only provide opportunities to make measurements of a range of quantities, but also to discuss why measurements can vary:

The circuit in Station 1 gives an opportunity to read a voltmeter. As pupils don't have to do anything to the circuit other than close a switch, any variations in the readings obtained are probably down to parallax error – where pupils have taken the reading from an angle instead of directly in front of it. If a digital meter is used, pupils can have difficulty with rapidly changing final numbers. If the circuit is left connected for a long time, it is possible that the values obtained will get lower.

The Station 2 activity is again a simple measurement using kitchen scales or a top pan balance. The issues here are the precision provided by the scale itself, and the variation in reading position.

Stations 3, 4 and 5 present difficulty because of learning to use a micrometer. The values for the two pieces of wood should show relatively little variation, but the sponge should show wider variation because the material will compress easily, so it is more difficult to judge when the micrometer is at the correct position before trying to read the scale.

Station 6 uses a measuring cylinder or a jug to measure the volume of water in the container. The issues in this case are to do with the precision offered by the scale on the jug or the measuring cylinder and also how pupils read the scale. The single pebble may result in more variation, depending on the equipment and method used. Pupils will get even more variation if they try to measure just one small stone, but if they calculate an average value from using 10 stones together there should be less variation. (If you didn't tell them to use all 10 stones, you could also ask how many stones they used for the measurement.)

Station 7 uses force measurements. You would expect the same object to give rise to identical readings when hung from identical force meters, but pupils should find one set of results skewed because the equipment was not zeroed. Dragging the object along the bench is likely to give a very odd set of results, because pupils will have different ideas of how fast to drag it and at what angle they should pull from: some photos would be very helpful here. It is also difficult to pull steadily and to read a scale that is moving, even if it isn't also changing at the same time.

Examples of questions about all the results

- Look at the results for (Station x): did everyone in your group agree on the value? If not, why was that?
- Which station's results showed the most variation? Why do you think that is?
- Which quantity did you find it hardest to measure? Why/what made it difficult? Could you have improved your measurement still using this equipment? Could you have improved your measurement if you'd used different equipment?
- Did any station's results show a steady change in the value (getting smaller or larger as you went down the column)? If so, why do you think that happened?
- Were any results different when you might have expected them to be the same? Why?
- Which measurements were most/least *precise*? Explain why.
- Which measurements were most/least *accurate?* Explain why.

Summary of precision, accuracy and variation for the teacher

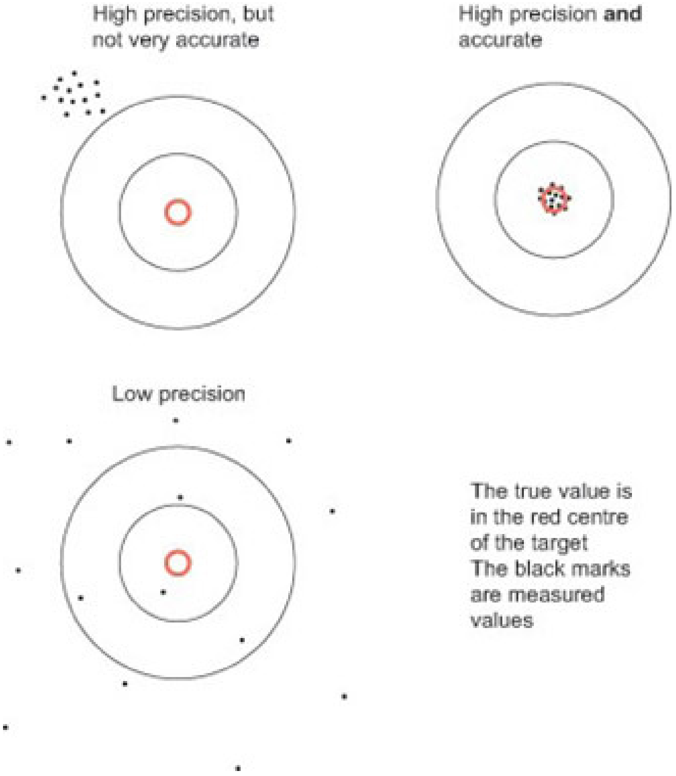
Why do measurements vary?

1. Variations caused by the equipment or by the way it is used:
   - The scale isn't fine enough for the quantity you are trying to measure.
   - The equipment produces variations in the reading which aren't due to actual changes in the quantity being measured.
   - The scale hasn't been zeroed before taking measurements
   - The measurements are not being taken in controlled conditions (e.g. there are draughts, changing temperatures).
   - Incorrect technique (e.g. not reading a scale from directly in front of the needle or indicator, or level with the scale marker).
   - Differences in technique/experimental method.
   - The equipment has been damaged.
2. Variations in the quantity being measured:
   - There is natural variation in the quantity – there is no absolute, 'true' value, e.g. length of a leaf, diameter of a seed in the sense that if you chose another leaf or seed the value would be different, no matter how carefully you measured it.
   - The value changes with time because of a factor that hasn't been considered in setting up the experiment (e.g. the length of a wire may change if the load is left on it, a previously desiccated object might show an increase in volume because it has absorbed water from its surroundings, another object might show a decrease in mass because of losing water to its surroundings, water fresh from the tap may be at a different temperature from water which has been standing in a room for an hour or more…).

'Accurate' or 'precise?'

Accuracy is about how close a measurement is to an agreed true value for specified conditions. A measurement is said to be accurate if it is close to the true value.

Precision is about how closely a set of measurements agree. A set of measurements that gives tight cluster of values is more precise than one with a wide variation in values.



Resource 5: Interesting facts about the earth

Background information / subject knowledge for teacher

This resource provides you with some information about the Earth and about Africa. Get your students to guess the answers. You can also get them to estimate things like each other's height and weight, the length of the room etc. Being able to estimate measurements is a useful skill in science as it enables scientists to spot errors.

If some of the students in your class are finding this topic easy, you could ask them to calculate the density of the Earth and the Moon.

Density = mass/volume

Volume = $4/3\ \pi\ r^3$ (π = 3. 142) r = radius

The Earth

Diameter = 12,760 km

Radius = 6,380 km

Mass = 5.972×10^{24} kg

Crust = 40 km thick

Distance from the Earth to the Sun = $1.\ 426 \times 10^{9}$ km

Distance from Earth to the Moon = 384,000 km

The Moon

Diameter = 3,475 km

Radius = 1,738 km

Mass = 7.35×10^{22} kg

Africa

Distance from the most northerly point (Ras ben Sakka in Tunisia) to the most southerly point (Cape Agulhas in South Africa) = 8,000 km

Distance from the most westerly point in Africa (Cape Verde) to the most easterly point in Africa (Ras Hafun in Somalia) = 7,360 km

Resource 6: Problem solving - solutions

Teacher resource for planning or adapting to use with pupils

Following are some possible approaches for some example problems from **Activity 3**:

Height of a tree

- Measure the length of the shadow and compare this with the length of a shadow cast by a metre rule at the same time. Use scaling to work out the height of the tree.
- Measure the length of the shadow and also the angle ϑ from the ground at the tip of the shadow to the top of the tree (Care: avoid looking at the sun!) then use
  - *opposite = adjacent x tan ϑ*
  - where opposite is the height of the tree and adjacent is the length of the shadow.

Mass of one sheet of paper

Find the mass M of x sheets of paper, then mass of one sheet = M/x

Area of the palm of your hand

Draw round your hand on a piece of squared paper and count the squares.

Volume of a stone

Displacement methods (see Station 6, Extensions 1 and 2 in **Resource 4**)

Thickness of a piece of paper

Measure the height (h) of a pile of x pieces of paper. One piece = h/x

Mass of a grain of rice

Measure the mass (M) of a pile of grains. Count the grains (x). The mass of one grain = M/x.

You will need to get several people to count the grains and keep checking until everyone agrees.

Pressure exerted by a student

A student stands on some squared paper and someone draws round their feet. The mass (M) of the same student is found in kg.

The force they exert (F) is the M x 9.8 and is in newtons. The area (A) of their feet on the ground is calculated by counting the squares.

The pressure = F/A.

Return to Science (secondary) page

Section 3: Pressure and heat transfer

Theme: Science lived – relevant and real

Learning outcomes

By the end of this section, you will have:

- used brainstorming to help students realise how the principles of pressure apply to everyday life;
- supported learners to use science ideas to explain local technology, household processes or agricultural processes
- supported your students in applying their knowledge of heat transfer in the home.

Introduction

Science is all around us. Activities like baking cakes, growing vegetables and mending a bicycle all involve scientific principles. Making connections between the science they learn in school and the things they do at home can help to reinforce the scientific principles that your students need to learn. It might also help them to understand some of the problems that they and their families face. **Resource 1** gives some strategies that you can use in order to help your students make these connections. This unit is not restricted to one topic area – we want to encourage you to develop the habit of relating the science that your students learn about to their everyday lives. You will use brainstorming as a technique for helping them to make connections and you will be encouraged to take them outside the classroom.

Students often see science as something that they do at school and not necessarily related to their lives. An effective way of demonstrating that this is not the case is to start with the everyday context and use it to draw out the scientific principles. Asking students about things outside school that are important can get them engaged and interested – especially if some controversy is involved. Most real-life situations are actually quite complicated and it is easy to find yourself talking about chemistry, biology or physics, or even wider issues. This will help to keep your students interested in science and help them to see how science can help them to understand the world.

1. Everyday examples of 'pressure'

In this unit we start with aspects of science that are relevant in the home, and move on to consider issues of wider importance to society. Sometimes the everyday applications for the topic you are studying are obvious, but sometimes they are not. If you ask an individual about how ideas about pressure manifest themselves in their lives, they probably would not come up with very much. But once they have the opportunity to talk in a group, you will find that the ideas will flow. **Resource 2** provides guidelines for conducting a brainstorming session in a large group; **Resource 3** provides lots of examples so that you can keep the discussion going. This approach would work with any physics topic that you have to cover.

Case study 1: Demonstrating pressure

Mrs Joyce walks into her classroom wearing her stiletto heels, carrying a wooden block with sharp nails stuck to it, a bottle of soda and a drinking straw, a blunt and sharp knife and two pieces of cake. She asked one of the students to walk with her outside the class on wet soft ground. She then asked the rest of the class to observe what happened to her shoes and those of the student. The students were keen to observe. She asked the students to support their observations scientifically.

Mrs Joyce had noted that the boys liked soda. She promised them that she would give the soda to any who would stand on the block with nails. The boys were not willing. Why did they decline? She asked them to give a reason. What is the best way to walk on nails? Hari commented that he had seen someone lying on a bed of nails at a circus.

Next Mrs Joyce asked two boys to compete at cutting the two pieces of cake; one using the sharp knife and the other using the blunt one. She wanted them to see which would produce the cleanest cut. She noted that the boys knew the winner before the competition started. How did they know the winner? Using the definition of pressure which the boys had learnt earlier they were able to give an explanation of each of the events.

Activity 1: Demonstrating everyday pressure

Gather your class round the front. Fill a cup up to the brim with water. Make sure the water is almost overflowing. Slide a piece of cardboard across the top. Holding on to the card, turn the cup of water upside down. The water will stay in the cup – make sure you practice before the lesson, or it could be messy! The card stays in place because of the air pressure. The pressure from the air is greater than the weight of the water. Ask questions to try and get your students to come up with an explanation.

Get your students to work in pairs to explain:

- how a straw works
- how a suction pad works
- why elephants and camels have large feet
- why it is possible to lie on a bed of nails.

Choose four pairs to report back.

Finish off with a brainstorm in which you encourage the class to think of other everyday examples of pressure.

2. Relating physics to everyday life

As you begin to make a conscious effort to link science in the classroom with everyday life, you will find numerous examples to support your teaching. It is a good idea to keep a notebook or file in which you record ideas or keep articles from magazines or newspapers. In order to emphasise the relevance of science, it is good to get outside the classroom. Resource 4 gives you some ideas of the sorts of places you could go to. **Case study 2** describes how a teacher took his class to a garage.

Case study 2: Visiting a garage

Mr Wekesa, an experienced teacher who had worked in a garage before joining teacher training college, wanted to break the monotony of teaching in the school environment. He decided that the students should visit a garage. Wishing to make science real and relevant, he first explained to the students using diagrams how a hydraulic lift works. The students drew the diagram in their books but he asked them not to name the various parts. After this he took the students to a modern garage opposite the school with a hydraulic lift. The students were first supposed to observe the parts and compare what they saw with the diagram they had drawn. The mechanic helped them to label the parts of the diagram.

Mr Wekesa discovered that most of the students in the class had visited the garage on their way to school but they had not realised how relevant the principles they had learnt in their physics lessons would prove to be. Mr Wekesa did a follow-up by asking the class to make a model of a hydraulic lift and presented it in a science congress competition. He commented that it was wonderful to see the enthusiasm in his class.

Activity 2: Visiting a playground

Choose somewhere near to your school where the principles of physics are apparent, for example a garage, with hydraulic jacks; building sites, with pulleys and levers; a playground with swings, roundabouts and seesaws; a farm with many simple machines.

Go along yourself the week before and make up a list of questions for your students that will make them think about the physics principles. For example, in a playground you could get them to think about what affects the periodic time of a swing, how to make a seesaw balance with a heavier and a lighter person, what forces you experience on a roundabout. On a building site or a farm, ask them to find examples of the ways in which the builders and farmers make use of machines such as pulleys, crow-bars and wheelbarrows to do heavy lifting.

When you get back to the classroom, ask them each to write a short report in which they explain how three physics ideas were being used.

3. How can we keep things cold?

Many of the problems that we face and decisions that we make in everyday life require some basic understanding of scientific principles. In **Activity 3** you will support your students in thinking carefully about a problem that they face everyday. There is no right answer to the problem and some groups of students will be more successful than others in providing a solution. **Resource 5** gives you some background information on the problem. This is an opportunity to encourage your students to write about their experiment in their own words. It is important for your students to develop their literacy skills in school, and this doesn't have to be in English or social studies classes. **Resource 6** provides a writing frame which will help your students to structure their ideas clearly. You should let your students look at and comment on each other's solutions. **Case study 3** shows how Mrs Ussaman organised the activity as a competition.

Case study 3: Organising an investigation

Mrs Ussaman had been teaching physics for a few years and found that when she related the ideas she was teaching to everyday life, her students were much more interested. When she started teaching about heat, she asked her colleagues at school to give her pieces of cardboard, material and plastic that they didn't need. By the time she came to the end of the topic she had a large collection.

One morning she gathered her class around the front and showed them a cup of ice cold soda. She challenged them to find a way of keeping it cold for as long as possible. The students worked in groups of five or six and made a plan. Mrs Ussaman gave them 30 minutes to plan and make their design. She gave each group a small piece of card and asked them to write a few sentences to explain how their design worked. She managed to borrow some alcohol thermometers from the local senior high school. Each group was given some water and two ice cubes. They measured the temperature of the water and recorded their reading.

The science lesson was at the start of the day, so the class gathered at lunchtime to measure the temperature of their cup of water and to look at each other's designs. Mrs Ussaman asked the headteacher to present a small prize to the winning group. They had dug a hole in the ground for their cup and made a lid from a piece of plastic bubble-wrap. The group that came second had wrapped their cup in a wet towel.

Activity 3: Carrying out an investigation

In the weeks before you do this activity, you will need to collect waste materials such as cardboard, plastic, cotton and paper. When you have taught your students about heat transfer, set them the task of designing a way of keeping water cool as long as possible. They should work in groups and plan their design before they start to make it. Encourage them to think about how heat is transferred and to apply their knowledge and understanding to solve the problem.

When they have a plan, provide them with a cup of cold water and the materials that you have collected so they can make and test their design. At the end each group should display their design and explain why it works. **Resource 6** provides guidance for your students to help them write a report on the problem and their solution.

Resource 1: Making science relevant to everyday life

Teacher resource to support teaching approaches

Making science relevant to everyday life

Introduction

The TESSA resources are underpinned by a view that science is not just an activity that is carried out by people in white coats in a laboratory. Science helps students to make sense of the world and they need to realise that it is taking place all around them. Many everyday activities involve scientific principles. It is important that pupils get the opportunity to apply their scientific knowledge to an understanding of their own environment and that they understand that the skills they develop in science are relevant to some of the problems they face in everyday life.

Possible strategies

Class discussion

Use local examples where possible, but also encourage pupils to draw on their own experience in the classroom.

Practical work

- Use local examples and materials, e.g. hibiscus indicator; local minibeasts for work on classification or adaptation; wood and kerosene to compare calorific content of fuels.
- Give pupils a challenge using scrap materials, e.g. obtain clean salt.

Research projects

Pupils could find information from local newspapers or magazines or interview adults in the community, such as brewers, mechanics or health workers. This could be the basis of a poster, oral presentation or role play.

Making use of the school grounds

Besides the obvious opportunities for ecological investigations, the school grounds are a source of teaching examples in other topics such as corrosion, structures and forces. Take pupils to see them or ask them to find examples or collect data for analysis.

Day visits

Visit local industries, agricultural sites or museums. The effective teacher will link this to classroom work both before and after the trip.

Homework

Ask pupils to write about examples of science around them (e.g. chemical change in the kitchen or forces on the football field) or to bring materials to the classroom.

Writing tasks

Use local issues as a stimulus for creative written work, e.g. a letter to a newspaper or radio script on local environmental or health issues.

Discussion tasks

- Interviews – one child could be the 'expert' and the interviewer can ask questions as if they were producing a news item for the radio.
- Pupils come to a decision about a local issue, e.g. health promotion or energy supply.

You should create a file for yourself and keep any newspaper and magazine articles that you find that contain or are about scientific issues. Every time you start a new topic, ask yourself how it relates to everyday life and help your students to make those connections.

Brainstorming

Brainstorming as a class or in smaller groups can help students to make connections between the science they learn in class and their everyday lives.

Resource 2: Brainstorming

Teacher resource to support teaching approaches

Brainstorming

Brainstorming is a group activity that generates as many ideas as possible on a specific issue or problem then decides which ideas offer the best solution. It involves creative thinking by the group to generate new ideas to address the issue or problem they are faced with. Brainstorming helps pupils to:

- understand a new topic
- generate different ways to solve a problem
- be excited by a new concept or idea
- feel involved in a group activity that reaches agreement.

Brainstorming is particularly useful for helping students to make connections between ideas. In science, for example, it can help them to appreciate the links between the ideas they are learning in class and scientific theories.

As a teacher, a brainstorm at the start of a topic will give you a good idea about the extent and depth of knowledge already held by the class. It will not tell you about individuals' understanding, but it will provide a wealth of collective ideas that you can refer back to as the topic progresses.

How to set up a brainstorming session

Before starting a session, you need to identify a clear issue or problem. This can range from a simple word like 'energy' and what it means to the group, or something like 'How can we develop our school environment?' To set up a good brainstorm, it is essential to have a word, question or problem that the group is likely to respond to. The teacher can gather the class round the board and run the session, or, in very large classes, divide the class into groups. The questions can be different for different groups. Groups themselves should be as varied as possible in terms of gender and ability.

There needs to be a large sheet of paper that all can see in a group of between six and eight pupils. The ideas of the group need to be recorded as the session progresses so that everyone knows what has been said and can build on or add to earlier ideas. Every idea must be written down, however unusual.

Before the session begins, the following rules are made clear:

1. Everyone in the group must be involved.
2. No one dismisses anyone else's ideas or suggestions.
3. Unusual and innovative ideas are welcomed.
4. Lots of different ideas are needed.
5. Everyone needs to work quickly; brainstorming is a fast and furious activity.

Running the session

The teacher's role initially is to encourage discussion, involvement and the recording of ideas. When pupils begin to struggle for ideas, or time is up, get the group (or groups) to select their best three ideas and say why they have chosen these.

- summarise for the class what they have done well
- ask them what they found useful about their activity. What did they discover in the brainstorming that they didn't realise before?

Resource 3: Everyday examples of pressure

Teacher resource for planning or adapting to use with pupils

Everyday examples of pressure

Following are some real-life examples of pressure in action:

- If you are carrying a heavy bag, narrow handles or straps cut into your hands and shoulders, but broad handles and straps are more comfortable.
- Narrow heels on shoes sink in further than wide, flat heels.
- Spreading your weight over a larger area stops you sinking in.
- Heavy vehicles that are used on softer ground need to have bigger, wider tyres.
- A sharp knife has a narrower blade edge than a blunt one, and is easier to cut with.
- Nails and tacks have a flat hammering head plus a sharp point to make it easier to hammer into wood, but also puncture tyres.
- Large machines for digging, grabbing or lifting *use* **hydraulic pressure systems***.*

Below are some everyday items that rely on pressure to work:

- suction pads
- sucking a drink up with a straw
- siphons
- syringes
- bicycle pumps
- water pumps
- hydraulic jacks for lifting cars
- pneumatic controls
- vacuum cleaners.

Resource 4: Examples of physics in action

Teacher resource for planning or adapting to use with pupils

Examples of physics in action

Places to visit and examples you might see

Place	**Examples**	**Physics principles they use**
Garage or workshop	Hydraulic jacks	Pressure = force/area and pressure is transmitted through a fluid (oil), so input pressure = output pressure Used as a 'force multiplier'
	Brace, screwdriver	Input force x input distance from axle = output force x output distance A force multiplier
Building site	Pulleys	Input force x distance it moves = output load raised x height it is lifted. A force multiplier
	Wheelbarrows and levers	Input force x input distance from wheel axle or pivot = output force x output distance from pivot A force multiplier
Kitchen or bakery	Can openers, potato chippers, nut-cracker	Examples of levers as force multipliers, so small force exerted by operator on the handle produces a large force on the object: Input force x input distance from pivot = output force x output distance
	Knives and skewers	Narrow blade edges and fine points cut into the material more easily because, for the same force, reducing the area increases the pressure
Playground	Seesaw	Another lever example: a lighter person sits further out to balance a heavier person. Clockwise moment = anticlockwise moment
Farm/garden	Shears/secateurs/ branch cutters	Force multipliers: Input force x input distance from pivot = output force x output distance

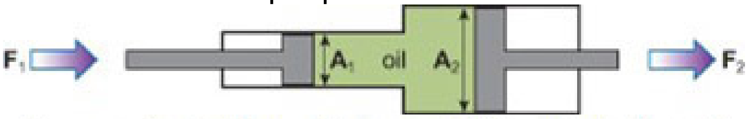
Some examples of force multipliers

Hydraulic jack:

You use a small force but push further to raise the large load a smaller distance.

Input pressure = output pressure
because the pressure is transmitted by oil.

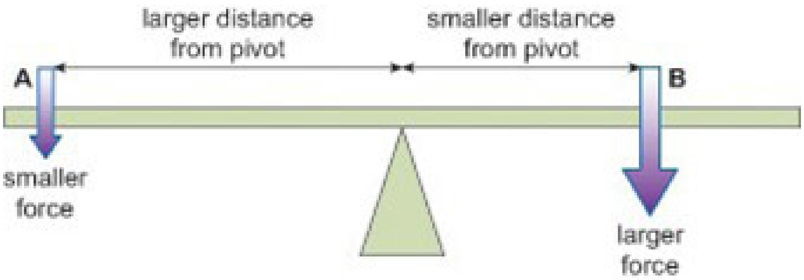
- narrow input piston cylinder with area A1 , small input force F1
- wider output piston cylinder with area A_2, larger output force F_2
- force on output piston



$$\frac{\textit{Force on input piston}}{\textit{Area of input piston}} = \frac{\textit{Force exerted by output piston}}{\textit{Area of output piston}} \quad \frac{F_2}{A_1} = \frac{F_2}{A_2}$$

Levers , e.g. see-saw:

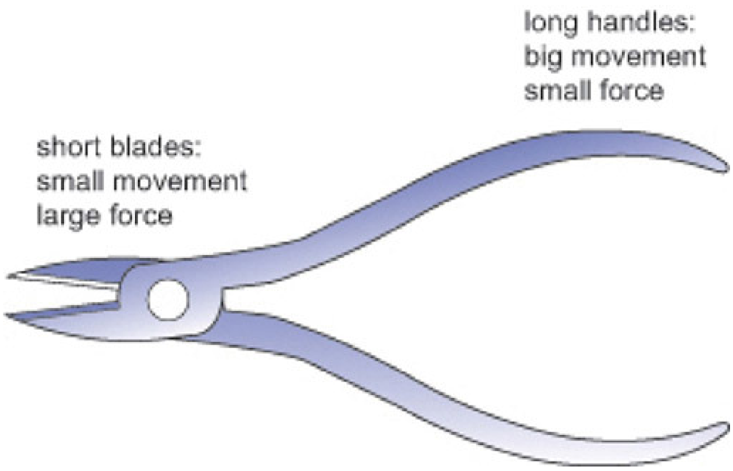
Clockwise turning force x distance from pivot = anticlockwise turning force x distance from pivot



$$\frac{\textit{Distance of person A from pivot}}{\textit{Distance of person B from pivot}} = \frac{\textit{Weight of person B}}{\textit{Weight of person A}}$$

Cutting tools e.g. secateurs, shears:

$$F_1 \times d_1 = F_2 \times d_2$$



Resource 5: Keeping things cool

Background information / subject knowledge for teacher

Background information on insulation and keeping water cool

- Energy (**heat**) is transferred from hot objects to colder objects.
- Anything that is warmer than its surroundings becomes cooler by transferring energy to the surroundings (so they get warmer); anything that is cooler than its surroundings becomes warmer (and the surroundings become cooler) as energy is transferred from the surroundings to the object.
- If you leave something long enough, it will reach the same temperature as its surroundings.
- To keep a hot object hot, or a cold object cold, you have to slow or stop the transfer of energy (heat).
- Energy (heat) is transferred by conduction, convection and radiation.
- Metals are good conductors but plastics, or materials with lots of air gaps like foams or bubble wrap, are poor conductors (or good insulators).
- **Using thermal insulation** or **insulating** a hot or cold object means wrapping the object in a material which is a poor thermal conductor.
- The thicker the insulation, the better it works. Don't leave gaps in the insulation.
- Heat (energy) is transferred through a fluid like air or water by convection currents. Convection currents rise above the heat source as the warmed air or liquid expands (because it is less dense than the air/water around it). As the air or liquid cools it becomes more dense again and sinks.
- Building designs can make use of convection currents to keep the building cool: to do this they allow warm air to rise through the building and escape from the top, drawing cool air in at the bottom.
- Shiny or white surfaces reflect most radiation, while black surfaces are the best absorbers and transmitters. To make use of solar heating you would use black surfaces to absorb as much energy as possible; to keep something cool, you use shiny surfaces (wrap them in foil, spray them with shiny paint) or white surfaces to reduce absorption.
- Vacuum flasks reduce heat transfer by all three mechanisms: the silvered layer reduces transfer by radiation, the vacuum means there is no air to allow losses by convection, and the insulating foam beneath the casing reduces losses by conduction.
- Thick coverings also help to keep cool things cool because it takes more energy to heat up the covering material. This is why buildings with thick stone walls stay cooler than buildings with thin wooden walls – there is more 'stuff' to heat up.
- Water has a high **specific heat capacity**, meaning it takes a lot of energy to raise its temperature, so it keeps the temperature steady for longer: rivers and lakes are slower to heat up than the surrounding land; leaving cold bottles in a bucket of water on the table keeps them cool longer than just leaving them on the table.
- When a solid melts, it absorbs energy from its surroundings but it stays at the same temperature until all the solid has turned to liquid. Changing from solid to liquid (or from liquid to gas) is called a 'phase change', and materials which need a relatively large amount of energy to melt are used in cooling jackets for transferring foods or medical supplies without refrigeration. (When used like this, or in the plaster of buildings to help keep rooms cool, they are called '**phase change materials**' or PCMs for short.)
- When a liquid evaporates, it uses energy from the surroundings to do so, so we can use evaporation to help keep things cool: letting the water evaporate from your skin instead of using at towel to dry yourself makes you feel cooler, and wrapping a bottle in a damp towel helps to keep it cool for longer.

Resource 6: Planning resource for students

Teacher resource for planning or adapting to use with pupils

How can we keep water cool as long as possible?

A cold drink straight from a fridge or chiller can be very refreshing, but it won't stay cold for long!

Work with your partner to design a way of keeping water cold in a hot climate. You will need to make and test your design, then present a report explaining how it works. Your report should include technical terms associated with heat transfer.

The writing frame below may help you. Structure your report by answering the questions:

Introduction and plan

What are you trying to find out?

What features do you think will be important? Explain how they could help. Include labelled diagrams of the designs you plan to test.

Describe how you will test your designs to find out which one is best. How will you make this a fair test? What measurements will you take?

Results and evaluation

Present your results in a table and using appropriate graphs or charts.

What do the results suggest? Why do you think this design worked the best?

Return to Science (secondary) page

Section 4: Forces

Theme: Problem solving and creativity

Learning outcomes

By the end of this section, you will have:

- used a game to help your students become familiar with the key words for this topic;
- planned activities that engaged students' thinking about forces
- given your students the opportunity to solve a problem.

Introduction

When your students start to look for a job, the qualifications that they have will obviously be very important. However, potential employers will also be looking for people who are creative and who are able to solve problems; they will be looking for people who can think for themselves. The case studies and activities in this unit are designed to show you how you can give your students the opportunity to be creative and to develop their 'thinking skills'. Some general strategies are given in **Resource 1** . You need to think about how you can create an atmosphere of excitement and enquiry in your classroom. If you can do this, students will ask questions and readily contribute their ideas. Students love dramatic demonstrations and amazing and unbelievable facts and will respond to your genuine enthusiasm about the subjects that you are teaching.

Creativity is about the ability to think, not just recall, but to apply, suggest, extend and model and create analogy. You can encourage your students to be creative by setting them open-ended tasks and giving them choices about how they present their work. For example, students who are particularly talented in the humanity subjects and who enjoy writing, might like to write about science in the form of a newspaper article or a poem. That would not suit everyone, so that is why giving students a choice can be very helpful. As a teacher, being creative doesn't necessarily involve dreaming up new and exciting activities – although it can do! Creative teachers can take ideas from these units or from their colleagues and adapt them for use in different contexts.

1. Developing literacy through Science

In this unit, the three activities would fit into your normal teaching of 'forces', but in each one you will be providing the opportunity for your students to talk about and think about the ideas.

Friction and air resistance are all around us and have a profound effect on everything we do. The purpose of **Case study 1** and **Activity 1** is to get your students to make the links between the forces around them and their everyday lives. **Case study 1** describes a teacher who worked jointly with an English teacher – the students discuss the ideas in science and then write a story in their English lesson (**Resource 2** provides information on promoting cross-curricular links and literacy skills). The focus of **Activity 1** is on helping your students to understand the scientific words.

Case study 1: Creative writing on friction

One of the misconceptions about friction that Mr Sifuna had noted in his many years of teaching was: 'Friction always hinders motion and therefore you always want to eliminate friction.' Mr Sifuna and his colleague Mrs Haule (English teacher) agreed to work together. Mr Sifuna divided his class into groups. Each group had a chairperson and a recorder. The students had to imagine and discuss how their daily work would be without friction and then decide whether to eliminate it or not. It was agreed that every idea that each student contributed would be recorded. Mr Sifuna walked around the class as the students discussed. There were heated discussions and the recorder was very busy writing the ideas. Mr Sifuna was surprised by how imaginative his students were and how many ideas they had at the end of 15 minutes.

Later, in English, when they were learning about creative writing, Mrs Haule asked the students to make up a story about a world without friction. When the students wrote their composition, it came out clearly that the misconception had been corrected. Friction must be reduced in some areas for life to be enjoyable but it can also be very helpful. What an exciting way to handle misconceptions! Mr Sifuna was very pleased to see that one of the students who found science difficult wrote one of the best stories.

Activity 1: Using a game to learn key words

One of the difficult things about science is the number of new words your students have to learn. It is a good idea when you start a new topic to spend 15 minutes specifically helping them to learn the key words. This would work for any topic.

Write the key words for the forces topic on pieces of an old cereal box. This could include push, pull, twist, squeeze, moment, air resistance, floating, sinking or upthrust. Ask a student to pick a card and then get them to mime the word. The rest of the students have to guess what the word is and the student with the card picks someone to write the word on the chalkboard and choose another word. If you do this for other topics you will build up a collection of cards that you can use for revision as well. If you work with a colleague, that would save you time.

2. Drawing diagrams to explain science

In science we often illustrate key ideas by drawing diagrams. The temptation is to get the students to copy the diagram off the board so that they learn the 'right' version. In **Activity 2,** you are encouraged to let the students draw their own diagrams to illustrate the forces involved in three demonstrations. **Resource 3** provides the necessary background. The case study shows how one teacher managed this in her classroom. During the demonstrations, you should prompt students to ask questions about what is happening. The act of asking questions requires engagement and creative thought, which is what we are trying to promote. You will also find that the students are more interested in the answers to questions that they have generated. **Resource 4** provides information on how to promote an atmosphere of enquiry in which students are encouraged to ask questions.

Case study 2: A Bungee jump

Miss Chitsulo was a student teacher on teaching practice. Her tutor was coming to visit in order to watch her teach. Miss Chitsulo knew that her tutor had a laptop computer so she asked her to bring the laptop and a projector from the college to the lesson. The week before, she went to an internet café and downloaded a film of someone doing a bungee jump from the bridge across the river Zambezi and stored it on a memory stick. In the lesson, she gathered the class around the front and showed them the film of the bungee jump. Miss Chitsulo asked lots of questions about what they thought it would feel like at each stage. She sent the class back to their places to draw diagrams to explain what they had seen.

They had to draw three diagrams of the bungee jumper to show the forces acting at various points in the jump – on the way down, at the lowest point and on the way back up. The class teacher suggested that they should copy the diagrams off the board, but Miss Chitsulo wanted to see if they could do it themselves. While they were working, she walked round the room and asked questions to prompt them to remember the discussion they had had. At the end, she asked volunteers to draw their diagrams on the board and gave everyone the chance to correct their own work. She chose people who she knew had got it nearly right. Her tutor also walked round the room and talked to the students. She was impressed by some of the questions that they asked.

Activity 2: Student-led demonstrations

In this activity, you will do three demonstrations: a spring balance (a newton meter) with a mass in water and in the lab; pushing a balloon into the water and a floating needle. See **Resource 3** for the details. Give the students the opportunity to volunteer to contribute to the demonstrations. Get the students to generate a set of questions about each demonstration. Write these on the board and discuss the answers as a class. Students should then be asked to draw pictures of each demonstration (or label pictures you have provided) using arrows to illustrate the forces acting. It is important to let your students draw the diagrams for themselves. Don't worry if they make mistakes – they will learn from the mistakes and are more likely to remember if they have thought about it for themselves. At the end, draw the correct diagrams on the board and ask them to correct their own.

3. Setting open-ended tasks

In order to learn to solve problems, students need to be provided with open-ended activities that have a number of solutions. In order to develop their ability to solve problems you can be selective in the information that you give them. A good problem solver knows which questions to ask. For example, you tell them at the beginning of the topic that you want them to explain why a large ship can float in water. Don't ask for the answer until the end, but make sure you give them some clues while you are teaching the topic. In **Activity 3,** you will set your students the task of changing the shape of a piece of Plasticine (or equivalent) to make it float. Once they have solved the problem, they should look at each other's solutions and should be prompted to explain their own thinking (**Resource 5** provides a writing frame that you could use). **Resource 6** describes an alternative problem that you could set and suggests how it could be adapted for students of different abilities.

Case study 3: Solving a problem

Miss Chitsulo set up a competition: 'Which "boat" can hold the most paperclips?' and gave each group a piece of Plasticine: all the pieces were exactly the same size. Every group tried out their idea and then the class gathered round the winner and worked out why it had won.

Some students commented on how the boats got lower in the water as more paperclips were added. Miss Chitsulo asked the students to predict what would happen if you put the boat into very salty water (or into oil) and to explain why they thought that. She had some salt water and oil ready for them to try their boats out. She knew that this would provide an opportunity to think about what is providing the upthrust and allow students to explore some ideas about forces, and maybe use some things they already knew about the way ships float higher when unloaded and when in salt water rather than in fresh water. After the students had tried the winning boat in different liquids, she showed them some photos of plimsoll lines on ships (lines marked on ships to indicate the depth to which a vessel may be immersed in water) and they talked about how this helps keep ships safely loaded.

Activity 3: Investigating floating and sinking

You will need a bowl of water and some objects of different sizes, shapes and materials. For each of the objects, get the class to predict whether it will sink or float. If possible, it would be good to have a small piece of a hard wood that sinks and a large piece of a soft wood that floats. Encourage the students to explain their predictions before you test them. When they try to explain their thinking, they might get a bit confused, but it will help them to learn. Think back to your own time at college – the things we understand best are often the ones which confuse us for a while! Demonstrate that a lump of Plasticine (modelling clay) sinks when you drop it into a bowl of water. Challenge the class to devise a way to make it float, and if it can do that, to carry a small load. At the end, explain why an object floats, in terms of the forces. Ask students why an ocean liner made of steel can float.

Resource 1: Problem Solving and Creativity

Teacher resource to support teaching approaches

Problem solving and creativity

Through being resourceful and engaging and providing variety, you will be able to motivate your students. If you are willing and able to solve problems and be creative, you will be able to help your students develop these skills. And it is not as difficult as it might seem!

Creativity

Creativity is about the ability to think. It is not just about remembering, but also applying, suggesting, extending, modelling, and offering alternatives. It is something that you can model for your students. Students need to be encouraged to think differently and come up with original ideas. They also need to feel confident in the reception they will get before they make such suggestions.

Some teachers will naturally be very creative, but some will not – and that is fine as long as you are resourceful and willing to try new ideas. A creative teacher, for example, will take the TESSA Secondary Science units and apply the strategies we suggest to different contexts. You could use news items from radio, television or newspapers and relate this to the science you are teaching. You can set open-ended tasks and allow students to make choices about how they present their work. You may take some risks in your teaching. Above all, you will create an atmosphere of excitement and enquiry with dramatic demonstrations, enthusiasm or amazing and unbelievable facts.

Strategies to promote creativity

Get students to:

- write a story to illustrate a scientific principle
- draw a picture to illustrate a scientific principle
- make up a play
- make a model
- take part in a role play (e.g. be the particles in a solid, liquid or gas)
- make up a poem or a rap
- think up alternative explanations for something they see
- write a letter or newspaper article or podcast.

Problem solving

Helping students to develop problem-solving skills is a frequently cited goal of science teachers. As with creativity, you can model these skills in your own classroom. For example, if you can't answer a student's question, you can come back next lesson with a solution and explain how you worked it out and why you found it hard. Being able to solve problems involves developing thinking skills. There are various strategies that you can adopt to help children develop these skills (Wellington and Ireson, 2008):

- **Encouraging student-generated questions.** The act of asking questions requires engagement and creative thought, two core cognitive strategies.

- **Being clear about 'purpose'.** Students should be encouraged to ask: what is this all about?' 'What does this relate to?' 'Why do you want us to do this?' – rather than embark on activities in an unthinking, recipe-following fashion.
- **Setting open-ended activities.** Teachers should set activities that can be tackled in a variety of ways so that children have to think about how they will tackle the problem.
- **Planning.** Teachers need to provide opportunities for children to plan their problem-solving strategy in a systematic way.
- **Paraphrasing.** It is well known that you really get to know and understand ideas when you try to teach them to someone else. Giving children opportunity to paraphrase an explanation will help them to understand difficult ideas and to be aware of their own learning.
- **Learning to learn (metacognition).** Teachers can encourage children to become more conscious of their learning by getting them to think about why they don't understand and what strategies helped them that might be useful in the future.

Reference

Wellington, J. and Ireson, G. (2008) *Science learning, Science teaching*. Abingdon: Routledge.

Resource 2: Promoting Cross-curricular links and literacy skills

Teacher resource to support teaching approaches

Promoting cross-curricular links and literacy skills

Cross-curricular links

Why promote cross-curricular links?

- It is important that students integrate learning across subjects, rather than seeing knowledge and skills as compartmentalised. Sometimes achievement in one subject can be limited because students don't realise that skills they learnt in another subject could be helpful.
- When you refer to what students learn in other subject areas, you are demonstrating that you are interested in their broader learning and that you value learning in general, not just science.
- By using a range of approaches, you can draw on strengths which students may not show in the course of a 'normal' science lesson. Opportunities to show creative and imaginative ability can motivate students who find science hard and prefer arts subjects.
- This is a two-way process: science provides support for learning in other subjects and beyond the school curriculum; science learning can benefit from skills and knowledge acquired and practised in other subjects.

Some examples of **topics** which might have a link with other subject areas

- the water cycle, erosion, pollution, mining, energy resources, climate
- growth and development, drugs
- food and nutrition
- famous scientists and inventors, important inventions and discoveries.

Some examples of **approaches** which may be more commonly used in other subjects:

- role play
- creative writing
- discussion
- producing a poster
- carrying out a survey or using a questionnaire
- practical problem solving
- designing and constructing an artefact
- using an internet search or searching reference books.

Some examples related to teaching forces:

- Bungee jumping – creative writing about sensations at different times in a jump.
- Surface tension – insects that walk on the water surface, creative writing or poster on life from an insect's point of view (effect of scale – like the raindrops in *A bug's life*).
- Floating and sinking – freshness and floating/sinking test for fruit; how do people check whether different foods are fresh? Opportunities for surveys, and for links to work in food technology/cookery.

- Floating and sinking – used as a way of sorting different types of plastic for recycling (pieces of plastic are put into a series of sorting tanks containing liquids of different densities e.g. water, salt water, glycerol), this might link to work in geography on resources, or work in technology on different materials.

Working with colleagues in other subjects

If you want to try a new approach, it is a good idea to work with a colleague who uses this approach in teaching their subject so you can learn how to use the approach effectively. For example, English teachers will be more used to organising a debate than science teachers; maths teachers often use peer marking; and humanities teachers often get students to do their own research, or tell stories in order to convey information. Discuss your plans for your own lesson with a colleague from another subject. For example, you might ask:

- What things do you need to have prepared before the lesson for this kind of activity? (e.g. does it work better if you have some photos, or something to listen to at the start?)
- Does the activity work better with a particular room arrangement (e.g. clear a space for role play, or everyone in a big circle to start a discussion)?
- Are there any routines or rules that you establish before this kind of activity?
- Do you have some standard phrases or instructions that students will recognise (like 'freeze!' or 'statues!' when you want students to pause in the middle of a role play)?
- What size of group works best for this activity? How do you choose who is in each group? (e.g. Before a group discussion, do you give everyone a role card?)

Promoting literacy skills in science

Why promote literacy skills through science?

- Literacy skills need to be developed through every subject and practised regularly.
- Language is often a problem in African countries because students are learning in English, which is not their first language.
- Improving literacy skills helps students to access materials more effectively, and helps to make them more confident learners.

What kinds of literacy skills are particularly useful in science?

- Students need to understand the key scientific words.
- Locating information from the internet, in newspapers and magazines, or in reference books or non-fiction books.
- Locating information quickly in a piece of text.
- Identifying key words and phrases in a piece of text.
- Producing a summary.
- Following a set of written instructions.
- Knowing the meaning of technical terms.
- Being able to work out what a new technical term might mean (by recognising related terms).
- Being able to spell technical terms correctly.

Below are some examples of how you can promote literacy skills:

1. Identifying key words and phrases in a piece of text

Possible ways of promoting this: Recognition – Search for identified key words (list provided by teacher); identification – write down a list of key words in a text (student identifies key words to make their own list).

2. Locating information in a piece of text

Possible ways of promoting this: DARTs activities – circle/highlight/underline the words (or phrases) that, for example, name a piece of equipment, are the parts that move, are stages in a process, tell you what to do, are units of measurement, tell you how it moves. (Note, if you have see-through plastic pockets you can put a photocopied sheet in, get students to use felts pens for this activity then wipe the plastic clean with a sponge when you've discussed the answers).

3. Creating a summary

Possible ways of promoting this: Selecting phrases or sentences that describe key information in the text (e.g. sorting sentence strips into two groups – correct/incorrect, true/false, text says this/text doesn't say this); sequencing sentences (on strips of paper) to create a summary; provide a writing frame to help students include the key elements in a sensible sequence.

4. Understanding technical terms; recognising families of words/ recognising word roots

Possible ways of promoting this: Make lists of 'related words' (words with a common root such as 'geo-' or 'chloro-') for the wall for each topic; students create their own glossaries for each topic; sorting activities – from a list of words or bag of words on pieces of paper, find all the words that are about…; matching activities – match term to meaning ('snap' card game); word searches – will help with spelling.

Resource 3: Force Diagrams

Background information / subject knowledge for teacher

Forces

This resource is for use with Activity 2.

Forces can change the shape of an object, can make it move faster or slower, or change the direction it is moving in.

If an object is not moving, or is moving at a steady speed in a straight line, then the forces on it must be balanced.

The bigger the force on an object, the bigger the acceleration (change in velocity) it produces. If something is accelerating (getting faster while moving in a straight line or moving in a curve) then the forces on it are not balanced.

Forces (and velocity and acceleration) are vector quantities – they have size and direction. (Scalar quantities like speed and mass just have size). We can show them as force arrows, where the arrows are drawn to scale and the length of the arrow represents the size of the force.

Note: In more advanced work, the combined effects of forces can be worked out by using force diagrams with all the force arrows drawn to scale. To find the size and direction of the combined effect (called the resultant force), all the force arrows are moved so they are drawn 'nose to tail', then the arrow from the start of the first arrow to the end of the last arrow is the resultant force arrow. The length of the arrow gives the size of the resultant force.

Using force diagrams with students

Asking students to draw diagrams of the forces acting on an object – or adding force arrows to an incomplete diagram – is a good way to explore what they think is happening, and to encourage discussion.

Providing pictures for labelling, rather than asking students to draw the objects, can help to avoid the problem of students worrying about their drawing ability or spending all the time making a pretty drawing instead of thinking about the science. The most important thing is for students to use arrows to identify the forces acting on an object and to show what direction they act in.

For older students, you can introduce some additional guidelines:

- Force arrows are straight arrows (not curved ones).
- The arrow should start from the part it is acting on, and points in the direction the force acts.
- The longer the arrow, the bigger the force.
- If two forces are balanced (so the object is either not moving, or is moving steadily) then the arrows will be the same size and start from the same point, but go in opposite directions.

- If two forces on an object are not balanced (so the object is accelerating), then the bigger force will be in the direction it is accelerating, and the arrow for that force will be bigger.
-

Identifying the forces acting on objects: some examples

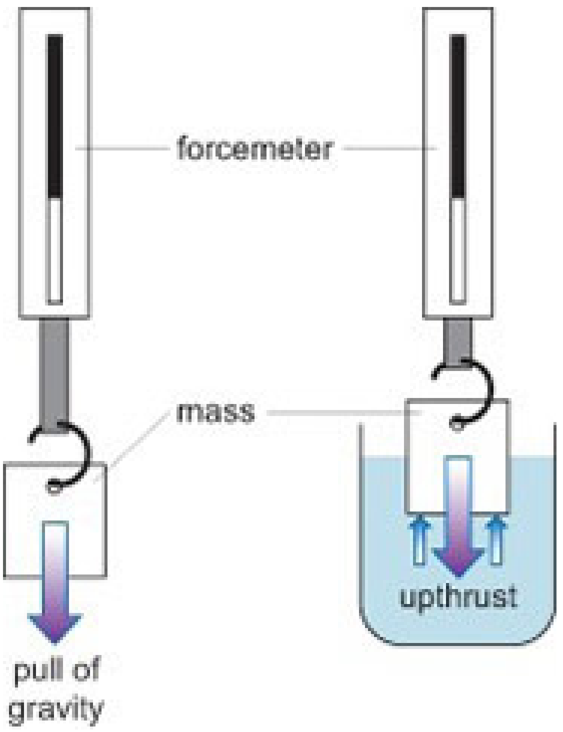


Diagram 1 A spring balance with mass hanging from it in air and in water.

The forcemeter in Diagram 1shows that a smaller force is pulling on it when the mass is in water.

The mass hanging from the forcemeter pulls down the spring less when it is in water.

The mass is unchanged: the **pull of gravity** on it (red arrow, shown on both diagrams) is the same in air and in water, so its weight is unchanged. It appears to weigh less because there is an **upthrust** force (blue arrows, only on the right hand image) on the mass.

The balloon in Diagram 2 has only a small mass, so the **pull of gravity** is fairly small. You have to **push down** to make the balloon go further under water. The further you push the balloon under water, the harder you have to push to keep it there.

As you push the balloon down, you can see the water level rise: the water that you push out of the way (displace) as the balloon goes further under water.

The amount of **upthrust** depends on the volume of water that is displaced by the balloon.

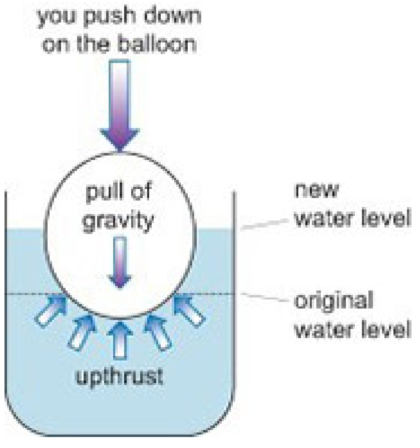


Diagram 2 Pushing a balloon under water

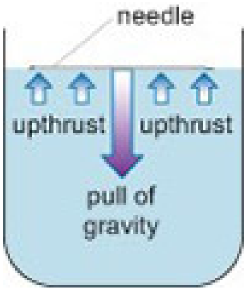


Diagram 3 A needle floating in water

A needle does not weigh very much, but it doesn't displace much water as it seems to lie on the surface; so what is keeping it up? There must be enough force pushing back up on the needle to counter the weight (Diagram 3).

Add a drop of detergent to the water. The needle should sink, because it was being held up by the surface tension of the water.

Identifying the forces during a bungee jump

There are three stages to consider:

1. On the way down
2. At the lowest point of the jump
3. On the way back up

1. On the way down, there is no tension in the bungee rope. The most significant force on the jumper is their own weight, due to the pull of gravity. Some students may also suggest air resistance, but this will be relatively small. Air resistance acts on the surface (think of the jumper pushing through the air as they fall).

2. At the lowest point in the jump, the tension in the bungee rope is at its maximum, and is enough to stop them falling any further.

3. The elastic rope pulls the jumper back up: the rope is no longer so stretched, so the upward pull from the tension is less.

Resource 4: Encouraging student questions

Teacher resource to support teaching approaches

Getting students to generate their own questions

For students to ask questions about something they are studying they need to feel that asking questions is a good thing, and that they won't be laughed at or thought stupid for asking.

Things you can do

You can encourage students to ask questions by giving replies like 'That's a good question! What do *you* think?', or 'Shall we find out?' or 'Hmmm… let's find out!'.

This raises two important points:

1. It is usually better *not* to simply give students the answer, but to encourage more thinking.
2. You need to have thought about the kind of questions that students might ask, so you have things ready in your room to try out ideas. This might mean a simple additional practical activity that would help students to understand the point more thoroughly, or might be a way of testing out their predictions, or it might mean using the internet or reference books to see if they have any answers. In the latter case, it is important to ask students to think about what are the key words or questions they might use in a search, and help them to rephrase those suggestions into something useful, rather than telling them what to look for.

Another way of promoting a spirit of enquiry is to have something set up and working, or some unusual items as 'talking points', so students can ask you 'What is that for?' 'What does this do?' and engage you in a conversation about it.

When something unexpected happens, it can make people review their understanding, so it is important to include demonstrations that include something which students will find surprising along with demonstrations that illustrate an important point. It is also important to ask students to predict what they think will happen before they see what *does* happen, and to be prepared to repeat an activity, so they can get the full benefit from this.

You can show that you value enquiry by being a role model. When something 'odd' or unexpected happens, let them hear you wonder why that was, and be ready to look for answers.

Resource 5: Structuring thinking

Teacher resource for planning or adapting to use with pupils

Solving problems – thinking about thinking

Here is a challenge!

A lump of Plasticine sinks if you drop it into a bowl of water, even if you lower it in carefully. How can you make the Plasticine float? Can you make it float so well it can carry a small load? How much can it carry?

Try out your idea, then compare your solution with other people's.

Describe what you did to make the Plasticine float.
What did you already know about that made you choose that solution? Did it work well?
Which design carried the biggest load? What was special or different about it that made it work better than the other designs?
Why could the best design carry a bigger load? What did you see happening as the boats were loaded that supports this idea? What else have you seen that supports this idea?
Predict what will happen if you put boat into salt water and load it again. How much load will it carry? What did you already know about that made you suggest this?

Resource 6: Extend and challenge

Background information / subject knowledge for teacher

Extending the work on floating and sinking to provide an opportunity for differentiation in a real life problem-solving context

This resource provides an extension to Activity 3.

The context and problem

Recycling is important for saving precious resources when the item can't be reused any more. Suppose you are trying to recycle waste plastics, how can you sort the plastics into different types so you can sell some of them to someone who can reuse them? (Plastic items have a recycling code on them which tells you what they are made of, but you can't always see this code on a piece of waste plastic.)

Background information

One method that recycling companies use to sort mixed plastic waste is **flotation**: different polymers have different densities, so while some will float in a particular liquid (because the polymer is less dense than the liquid) others will sink (because the polymer is more dense than the liquid). If you use three different liquids – water, saturated salt solution and glycerol (propane-1,2,3-triol) – you can sort most polymers.

The common polymers and liquids (shown in bold) are listed here in order of increasing density:

PP (polypropylene), PE (polyethylene), **water**, ABS (acrylonitrile butadiene styrene), polystyrene, **saturated salt solution**, PMMA (polymethyl methacrylate, also called acrylic or perspex), PC (polycarbonate – density varies), **glycerol**, PC (polycarbonate – density varies), PET (polyethylene terephthalate), PVC (polyvinyl chloride).

How the process works

All the plastic waste is chopped up into small pieces before the batch is added to the first tank (water, the least dense of the three liquids). (This is important because the lid and bottle of many plastic bottles will be made from different materials, and because if you use a whole bottle, it has air in it so you are not looking at the density of the plastic but of the bottle.) All the bits that float are skimmed off, and all the bits that sink go into the next tank, and the process is repeated. (Notice that, depending on what was in the original mix, you might have one type of polymer or you might have two or even three polymers in each of the final, separated groups, and you might have to use other tests to work out what bits were a particular polymer: you can't tell polyethylene and polypropylene apart by this method because they both float in water.)

Setting a differentiated task

You can control the amount of challenge by:

- the way you word the task
- the materials you provide and how you provide them
- the amount of information or guidance you provide.

Some different ways of setting the task

You will need to provide beakers or bowls for testing samples with each liquid. 'Samples' should be small pieces of clean plastic. You will also need to provide something to collect items that sink from the bottom of the container, and some cloths or paper towels to wipe up spills, and so students can wipe samples dry before putting them into the next liquid. It works best if you test samples one at a time, or you could leave students to find that out for themselves…

- Provide some identified samples and some 'mystery' samples, and ask students to identify the 'mystery' samples. This is a simple comparison or matching task.
- Provide some identified samples and ask students to explore which ones float and which sink in each liquid, then make an identification key. The more polymers, the harder the task.
- Provide unknown samples and the information about relative densities, and ask students to suggest what each sample is. The difficulty depends on what samples you provided and what you tell students about them. Deciding if a sample is *x* or *y* is easier than identifying with no possibilities suggested.
- Provide unknown samples and the information about relative densities, and ask students to suggest what each sample is *and evaluate the method*. This adds a different demand because students have to think about what the strengths and weaknesses are. (Was it easy to make a decision about which samples floated each time? What problems are there if you try to test several samples at once? Could they identify all the samples, or only say a sample 'might be x or y'?)

Some things you could use as sources for different types of polymer

Note: These are suggestions based on what the polymers are usually used for. Try to find the recycling code on the object to confirm what the polymer is.

PP polypropylene: bottle tops, some cosmetics bottles, yoghurt pots, some food trays

PE polyethylene: bleach or detergent bottles, bottles for still drinks, some cosmetics bottles

PET polyethylene terephthalate: shampoo bottles, fizzy drinks bottles

PVC polyvinyl chloride: plastic pipes and cable sheaths

PS polystyrene: plastic cutlery, 'foam' food cartons, drinks cups

PMMApolymethyl methacrylate (acrylic, Perspex): plastic rulers, clear drinks cups.

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Section 5: Electricity and magnetism

Theme: Dealing with challenging ideas

Learning outcomes

By the end of this section, you will have:

- structured an activity to probe understanding of the topic and to help your students understand the key words;
- supported your students in understanding the topic through active listening and talking;
- organised a role play to model electricity flow and worked as a class to evaluate the model.

Introduction

Being an effective science teacher involves being able to explain difficult ideas very clearly. There are a number of topics in science that are difficult to understand and difficult to explain because the ideas are abstract and based on things that we cannot see. Students often have ideas about science that are 'wrong', particularly about the more abstract topics. Just explaining the 'right' idea might work in the short term, but often doesn't last until the student has to take an exam. The 'wrong' ideas need to be identified and tackled before progress can be made. Often, simply explaining the ideas is not enough; you need to revisit them and consolidate understanding.

In this unit, the three activities build on each other and will enable you to help your students gradually develop their understanding. The first activity focuses on literacy and making sure that your students understand the key words. The second and third activities use different approaches to developing understanding.

1. Focus on literacy

Electricity is a topic about which there are many misconceptions. These are explained in **Resource 1** . Students find it very difficult to visualise how electricity works. If they can be supported in constructing a reasonably accurate model in their heads, then as they move on to more demanding ideas such as 'potential difference' and 'power', they will have more chance of being successful in this topic. Linked to electricity is magnetism, which can also be problematic for students.

This theme draws heavily on the ideas in 'Probing students' understanding'. It is particularly important that for difficult topics with known misconceptions, you find ways of identifying what your students are thinking. Your students will probably have been taught some basic electricity at primary school – but you need to check what they know. A significant barrier to understanding the science can be the scientific words that students need to know, especially if they were taught in their own language. **Activity 1** describes how you might support your students in understanding the key words associated with this topic. The teacher in **Case study 1** had very little equipment and so had to manage with everyday objects.

Case study 1: Word cards

Mrs Immare is concerned that her Form 1 class is finding learning in English, challenging. It is made more difficult by the fact that she has very little equipment. Before she started the topic on electricity and magnetism, she worked with her colleague and they made a list of all the words that their students needed to understand. (**Resource 2** has some suggestions.) Using an old cereal packet, the pair made a set of small cards. They wrote one of the key words on each of the cards and put them in a small box.

Mrs Immare gathered her class around the front of the class. She had arranged on the front desk some objects that use electricity – a torch, a mobile phone, and a radio. She also had some wire, two magnets and electrical components that she had taken from a broken radio. She used the objects to ask questions based on what she thought they should know already and to explain some of the key words. She drew a diagram on the board to show the electric circuit inside the torch.

Then she asked Ernest to pick a card and to read the word. She asked for volunteers to explain what it meant using the objects or diagram on the board. Loli got it right, so she picked the next card. As they got more confident she let the student who had picked the card nominate someone to explain the meaning. Everyone had to concentrate hard in case they were the ones that were picked.

Activity 1: Getting students to explain words

Before the activity, prepare a set of cards with some key words associated with the topic. Collect any equipment that you have on the front desk. Gather the students round the front and ask questions to find out what they already know about electricity and magnetism. Get the students to come and make a circuit and explain how to make the bulb light. Show them the attraction of two magnets and ask someone to make them repel each other.

When you have covered the main ideas, give the cards out, making sure that no one sees them. Each student who has a card has to come to the front and explain the meaning of the word – without using the word. The rest of the students have to guess what word they have. They can use the equipment or actions to help them explain the word.

2. Discussing key ideas in groups

Researchers have established a clear link between language and learning. When students discuss ideas with peers, they have time to draw on their memory of what they have done before, share ideas with their partner and clarify their thoughts by having to explain them to others. It also helps them to get used to scientific words which might not be familiar to them. You get the chance to listen to what they are saying and look at what they are writing, so that you are aware of their misconceptions when you plan your questions at the end. You are far more likely to address their misconceptions in this way. Too often when we use questions in a whole class discussion, we assume that because one student can give us a correct answer, the class as a whole understands the topic well. To show that you can use this technique in different contexts, the teacher in **Case study 2** gets her students talking about magnetism. **Activity 2**, which is based on circuits, will take more time than simply explaining the different types of circuit to your class and asking them to copy labelled diagrams and notes, but it will help the students to consolidate their understanding..

Case study 2: Talking about magnetism

Mr Sifuna knows from past experience that students find it difficult to understand the difference between 'being magnetic' and 'being a magnet' and that they tend to think that all metals will be magnetic. He started the lesson by talking to them about recycling materials. Some students have seen huge electromagnets lifting cars at a local scrap yard. Mr Sifuna showed the class some materials for sorting and asked them to discuss in groups which ones the magnets would pick out. He included empty drink cans, empty food cans, plastic drink bottles, plastic bottle tops, metal bottle tops and pieces of scrap metal. When everyone had made their predictions, he gave each group a bar magnet and asked them to sort the materials into 'magnetic' and 'non-magnetic.'

Some of the students were surprised that some of the metal samples were not magnetic.

He then gave each group two magnets, an iron nail, some paper clips and some pieces of copper. He set the question: what is the difference between a 'magnet' and a 'magnetic material'. He encouraged them to experiment with the materials and went round listening to their discussions.

Finally he showed them how an iron nail can be made into a magnet by stroking it in one direction with the bar magnet. Some of the students wanted to know how to separate plastic from copper and aluminium if they are not magnetic (see **Resource 3**).

Activity 2: Talking about circuits

In exams, students often have to draw or interpret circuit diagrams. They are more likely to do this successfully if they understand the diagrams; simply getting them to copy them down is not the best way to ensure they understand.

Divide your class into groups of six. Give two students in each group a set of descriptions of circuits (**Resource 4**). One of them reads a description and the other students work in pairs to draw the circuit as described. When they have done five, the students doing the reading out should check the answers. If the pairs disagree then they discuss it as a group until they all agree on an answer. You can extend the exercise by adding ammeters and voltmeters and asking students to work out the current and voltage in different parts of the circuit – depending on your exam syllabus.

3. Modelling electric circuits

Difficult ideas can often be helpfully illustrated using a physical analogy. This can make something that is very abstract feel concrete and can help the students to understand. The danger, of course, is that an inaccurate physical representation can introduce more misconceptions and difficulties at a later stage. When you are using physical analogies, you should always get your students to discuss the merits of the particular model. By identifying the shortcomings of the model, you will also add to their understanding. In the case of electricity, there are two models that you can use. The teacher in **Case study 3** has tried role play before and feels confident about using role plays in her lessons. She uses both models and encourages her students to decide which one is the best. **Activity 3** describes a role play that your class should enjoy. **Resource 5** provides some example role plays and instructions for carrying them out.

Case study 3: Evaluating models

Miss Chitsulo is a student teacher. She wanted to use a role play exercise to explore models with her students as one of her college assignments. She decided to try out two different role plays with her class, so they could discuss what is good about each model. First she tried out the ‘sweets and cups’ role play with a group of students. She checked that everyone in the class understood how the role play models what is happening in an electric circuit. She asked the students who were watching to explain what each part of the model represents. Then she used a different group of students for the second role play, which uses a rope loop. When they had tried both role plays, Miss Chitsulo asked her class to compare the two.

She asked some questions: ‘Is this a good model? How is it not so good? Why do you think that? Which one did you find easier to understand? Which one would you use if you wanted to explain about circuits to someone of your own age who had not learnt about them?’ Her students enjoyed the role plays and were pleased to be asked their opinions. Miss Chitsulo’s tutor was pleased that she had got her class so involved in thinking about a challenging topic.

Activity 3: Organising a role play

Choose one or both of the role plays described in **Resource 5** and prepare your resources before the lesson. For the ‘sweets and cups’ role play, you will need two paper cups, two boxes, and a packet of sweets with wrappers and for the ‘rope’ role play, you will need a rope two or three metres long, with the ends fastened together to make a loop. Explain to the class that they are going to use a role play to model what happens in an electric circuit and that at the end of it you will want them to be able to describe the model and what things it helps to explain. Choose students to take part in the role play, and ask everyone else to watch and listen carefully. Ask questions about the role play as it is going on. Get the students to explain which aspect of the circuit is represented by the different parts of the model. At the end bring everyone together to discuss the strengths and weaknesses of the model. Ask everyone to write a short paragraph to explain the model in their own words.

Resource 1: Common misconceptions

Background information / subject knowledge for teacher

Misconceptions about magnets and magnetism

Researchers have discovered that there are certain misconceptions about electricity and magnetism that are very common. We have summarised them here, so that when you plan your lessons, you can make sure that you address these misconceptions.

Misconception: all metals are attracted to a magnet

Not all metals are attracted to a magnet. Copper, aluminium, gold and silver are all metals, but they aren't attracted by a magnet. Iron, steel, nickel and cobalt are. Alloys containing these metals can also be attracted to a magnet – 'copper coins' attracted to a magnet are not actually copper but a copper–nickel alloy.

Misconception: if something is attracted by a magnet, it is a magnet

Being attracted to a magnet does not mean that a material is a magnet (but it is a magnetic material and can be made into a magnet). If something is attracted to a magnet, turn the magnet round and try again: if the object is repelled by the magnet this time, then the object is a magnet, too.

Misconception: the Magnetic North Pole, i.e. the pole of the earth in the northern hemisphere, is magnetically a north pole

North poles of magnets are the poles that point to the north. Like poles repel, unlike poles attract, so the Earth's Magnetic North Pole is actually a magnetic south pole, because it attracts the north pole of a magnet!

Misconceptions about circuits and electricity

Misconception: you only need one wire to make a circuit with a battery and a bulb

If students have seen an electric light hanging by a cord from the ceiling or electrical equipment with a lead to a plug, but have never constructed a circuit with batteries and bulbs, then they may think this. (They may also think that if you use two wires, the wire from one end of the battery is the one that counts and the other one is just there as a 'return route'.) There must be a connection from each end of the battery to two points on the bulb holder (i.e. the metal, not the glass) for the bulb to light.

Misconception: current is 'used up' as it flows round the circuit

Current is not used up: the current is the same all the way round a series circuit. If current is used up, then bulbs near the 'start' of the circuit should be brighter than those near the 'end'. Providing the bulbs are identical, then they will all be the same brightness.

Misconception: current starts from one end of a battery and flows through each component of a circuit in turn, until it gets back to the other end of a battery (e.g. battery to wire, then bulb, then wire, then bulb, then wire back to battery)

Current flows instantly in all parts of a circuit when there is a complete circuit. Even if you had a huge circuit going right round the classroom, all the bulbs in it would light up at the same time, not one after the other.

Resource 2: Focus on key words

Teacher resource for planning or adapting to use with pupils

Some key words for electricity and magnetism

Here are some key words that you could use. You might want to add some more, depending on your syllabus:

Electricity

Current

Charge

Cell

Battery

Circuit

Resistor

Switch

Lamp

Wire

Voltmeter

Ammeter

Magnet

Poles

Attraction

Repulsion

Magnetic field

Resource 3: Background to magnetism

Teacher resource for planning or adapting to use with pupils

Magnets, magnetic materials and non-magnetic materials

Questions for students to predict the answers to before they test their predictions

Will a magnet pick up all the materials?

What do all the magnetic materials have in common?

Will the magnet attract or pick up a piece of aluminium?

Will the magnet attract or pick up a piece of iron?

How can you tell the difference between a magnet and a magnetic material?

Additional question and what you need to answer it

How can you find the north pole of a magnet?

In order to find the north pole of a magnet, you must either

- have another magnet with the north pole marked on it (and which you know is correct – see below) *or*
- know which way is north.

You need a piece of string to suspend your magnet.

What you will need for each group to sort the samples

- At least one bar magnet for testing the samples.
- At least one other magnet to be a sample. This could be another bar magnet, but there are other magnets you could use, too: a ring magnet from an old or broken loudspeaker, a magnet from an old motor, a fridge magnet, a magnet from a magnetic door lock, a small magnet used for earrings or jewellery fasteners or from some handbag closures.
- Small samples of non-metallic materials, e.g. a piece of wood, a piece of cardboard, a piece of plastic.
- Small samples of metallic materials or objects made of metal: try to get a range of metals, e.g. piece of copper sheet or copper pipe, piece of aluminium/aluminium foil/empty aluminium drink can, piece of steel/empty steel food can/steel paper clips, iron nails.
- Two trays.

Before the lesson, put all the samples for a group on a table, spread them out as much as possible and mix them up. (If you have several magnets, make sure they don't attract other items on the table!)

Sorting the samples

One person in the group should hold one end of the 'tester' bar magnet above each sample in turn (but don't touch the samples with the magnet). They should decide whether the sample is attracted or repelled or neither of these.

Someone else in the group should remove all the items that are not attracted to the magnet or repelled by it and put them on a tray. (This should have all the non-magnetic materials.)

The student who has the magnet should turn the magnet round to use the other end and hold the end of the magnet over each of the samples left on the table.

Someone else should remove any samples that are not repelled by the magnet, and put them on another tray. (This should have all the magnetic materials on it. The only objects left on the table should be the magnets.)

Resource 4: Information on circuits

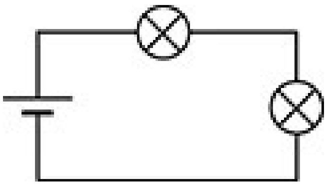
Teacher resource for planning or adapting to use with pupils

Suggested circuits and descriptions

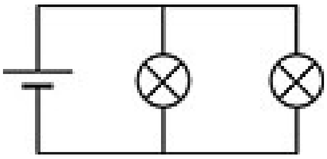
This resource is for use with Activity 2. You can add more of your own that apply to your syllabus.

A circuit with one cell (battery) and a bulb.

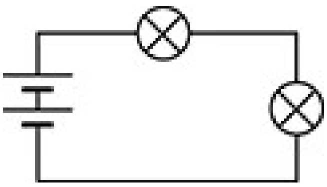
A circuit with one cell (battery) and two bulbs connected in series.



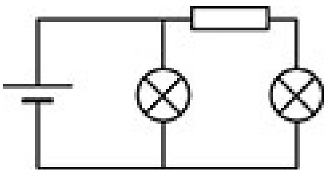
A circuit with one cell (battery), and two bulbs connected in parallel.



A circuit with two cells(batteries) and two bulbs connected in series.

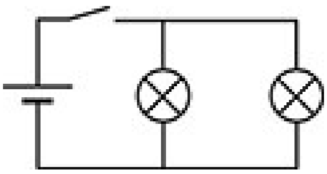


A circuit with one cell and a resistor, where one bulb is connected in series with the resistor, and the other bulb is connected in parallel with them.



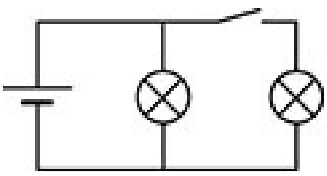
A circuit with one cell and two bulbs in parallel, with a switch controlling both bulbs. *Or*

A circuit with one cell and two bulbs in parallel, with a switch between the bulbs and the battery.



A circuit with one cell and two bulbs in parallel, with a switch controlling just one of the bulbs. *Or*

A circuit with one cell and two bulbs in parallel, with a switch on one of the branches.



Resource 5: How to model electric circuits

Teacher resource for planning or adapting to use with pupils

Teacher instructions for role play

Here are two role plays you could use to model what happens in an electric circuit with a small group (for use with Activity 3).

Note: In the descriptions, the different parts of the role play are explained ('this person is the battery', 'this is charge moving round the circuit', etc.). When you use these models with students, you might decide not to tell them all of this, but just say that this is a role play to model what happens in an electric circuit. Tell everyone in the role-play *what to do*, then ask them questions like, 'Who is the battery?' 'What represents the moving charges?' 'What represents the resistance?' or 'How does this show that energy is transferred?'

Sweets and cups

What you need: a packet of wrapped sweets, two boxes, and some paper cups.

What to do:

- Start with everyone except one in a circle. The one outside the circle is an observer.
- One person (the battery) has a box with some wrapped sweets in it: they pass one sweet every second to the person on their right, who immediately passes each sweet to the person on their right, and so on. (It may help to have someone outside the circle keep time for this by tapping the table once a second.)
- One person in the circle has a cup. They represent a lamp or a resistor. When a sweet arrives, they hold it in the cup for a second before they pass it on. Soon, all the sweets in the box are moving steadily around the circle. The observer stands behind the person on the left of the 'battery' and claps every time the person they are standing behind passes a sweet back to the battery. The rate the sweets are moving around is the current. Allow the sweets to go round several times, so that everyone settles into the rhythm before you make any changes.
- Now give a cup to a second person, so there are now two lamps/resistors in the circuit. What happens to the rate that sweets pass round the circuit (how often the observer claps) now?
- Now give someone else in the group a box, and half of the sweets. They also pass one sweet a second, so now there are two people passing sweets to the rest of the circle, so there are two sweets a second being passed). This increases the rate that sweets pass round the circle, and the observer claps twice as fast.

This model is good because you can see that the number of charges moving around stays the same. It is also good because you can see that increasing resistance reduces the current. Adding another battery increases the current as you would expect. There is a risk, however, that students will think that adding batteries adds more charges, although you have not got any more sweets moving round than before: focus attention on the rate at which sweets pass the observer. (Alternatively, just keep one person as the battery, but tell them to pass round sweets at twice the rate, i.e., pass a sweet every half second. This is harder to keep up: if you have someone keeping time, then get them to clap at twice the rate they did before.)

Ideally, the sweets would get a little bit smaller every time they passed the ‘lamp’, representing the transfer of energy to the lamp. Eventually, the sweets would be used up – representing the battery running out of energy. This is one feature of an electric circuit that is not represented very well in this model: the transfer of energy from the circuit to the lamp. The second model is better in this respect as students can ‘feel’ the energy as heat is generated by friction.

Rope
What you need: a (large) loop of rope, ideally with a pattern or marks on it every metre, so you can see how fast it is moving round.

What to do:
- Everyone in the group stands in a circle, so that the rope loop is not pulled too tightly, but does not sag anywhere either.
- One person is the battery: they pull the rope around *steadily, i.e. with a steady amount of pull*. When they pull, the rope should start to move round, and everyone in the circle should feel it move at the same time. The moving rope represents moving charge: charges around the circuit are all moving at the same time.
- Everyone else is the resistance: they grip the rope very lightly as it moves round, to slow it down. As the rope moves through their hands, their hands will be warmed by friction with the rope; and the more tightly the ‘resistances’ grip the rope as it goes round, the more energy is transferred to their hands (beware of sore hands and friction burns caused by people tugging the rope). More grip is meant to slow the rope down, to model how increased resistance gives a smaller current. (This is not a tug of war game: the ‘battery’ is meant to give a constant amount of pull, and should not start pulling harder and harder against the resistance.)

This model is good because it shows that when the current flows around the circuit, the charges are all moving round the circuit at the same time. It also links resistance with energy transfer, and shows that bigger resistance gives a smaller current. *However*, if the ‘battery’ starts to pull harder to move the rope round, then students might think that adding more resistance will make the battery work harder to keep the current the same.

For each model you should ask the class:
- What forms the circuit in this model?
- What represents the charge moving round the circuit?
- What represents energy in the circuit?
- Where does the current collect energy?
- Where does it give up energy?
- In what ways is this model similar to your own ideas about electricity? In what ways is it different?
- Which model is better?

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