TEMI

The Book of Science Mysteries

CLASSROOM SCIENCE ACTIVITIES TO SUPPORT STUDENT ENQUIRY-BASED LEARNING

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TEMI

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SUPPORT STUDENT ENQUIRY-BASED LEARNING

Welcome to the TEMI Book of Science Mysteries

In this volume, you will be able to explore a range of inspiring teaching materials selected from across a range of subjects. These materials are used in teacher training colleges throughout Europe to support enquiry-based learning in the sciences. The mysteries presented cover different topics, cater for a range of ages, and don't require complex classroom resources. Each mystery has been tested in the classroom and can help your pupils engage with and learn from enquiry-based study in science, technology, engineering, and mathematics (STEM).

What's special about TEMI teaching?

TEMI is an EU-funded project that uses the intrigue of mysterious phenomena to engage students and help them to become more independent learners. The TEMI teaching methodology incorporates four key innovations: first, the use of mysteries to capture students' imagination and motivation; second, the 5E cycle to help pupils explore and evaluate their learning; third, presentation skills to allow teachers to feel comfortable with presenting mysteries in the classroom; and finally, a method by which the responsibility for learning is transferred gradually from the teacher to the student, which flips the traditional learning channel.

Using this book and the worksheets

This book contains a series of mystery classroom activities, all of which introduce, explain, and provide examples of the four TEMI teaching innovations (mystery, a structured 5e learning cycle, presentation skills, and the gradual release of responsibility for learning to the student), with practical suggestions and worksheets for you to use in the classroom. We also include two examples of student lifelines: a student hypothesiser lifeline and a construct explanations lifeline - as well as an activity characterisation sheet. Using the hypothesiser lifeline, students can follow through and reflect on their learning process and proceed in stages, from a working hypothesis to data collection to acceptance or rejection of the current hypothesis. The characterisation sheet is designed to facilitate the use of TEMI activities according to the four innovations. These useful sheets can be deployed as they are or adapted to your own needs.

Online resources

A significant number of resources are also available on the TEMI website, including more classroom mysteries and links to a smartphone application that you may find useful both inside and outside the classroom. You might also want to read the companion book "Teaching the TEMI Way" (TEMI, 2015), which is available on the TEMI website in a number of European languages. This volume focuses solely on the theory and practice of the TEMI method. We wish you good luck as you explore the mysterious. We hope you find "The Book of Science Mysteries" interesting and useful, and that it helps you to build enquiry-based learning into your teaching activities.

Please send any feedback to **temi@qmul.ac.uk**

THE STUDENT WORKSHEETS THAT YOU WILL FIND IN THIS BOOK CAN BE COPIED AND USED IN THE CLASSROOM

Note that, in some cases, answers to earlier questions may be found later in the student worksheet. If this is inappropriate to your teaching style, you are encouraged to modify the student worksheet.

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The Book of Science Mysteries

Red or blue flowers?

What's the mystery?

The teacher couldn't decide whether to wear a red flower or a blue one, so they decided on a compromise: a half red, half blue flower! But something like that can't be natural, can it?

DOMAIN(S)

Biology.

SUBDOMAIN KEYWORDS

Water in plants, water transport in plants, capillary action, osmosis.

AGE GROUP

14 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation: **40 min.**

Approximate time in classroom: **two 45 min. lessons.**

SAFETY/SUPERVISION

No restrictions needed.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» White flowers (works best with carnations)
» Coloured ink
» Glasses/beakers
» Various materials the students can use for their experiments (see the teacher materials).

LEARNING OBJECTIVES

Physiology of plants, anatomy of plants, cell biology, osmosis, diffusion, capillary action.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher shows the students a flower that is half one colour and half another (prepared beforehand*) and asks them how this can be so. The teacher also tells a story about overhearing two boys talking about how the flower could have been created. They were discussing the drinking regime of plants when one of them said that he heard that a tree can bring 500 litres of water from the ground to its topmost branches. The boys wonder how this occurs. The class is invited to consider what this has to do with the strange flower.

*** Split a flower's stem in half (works best with carnations) and put each half of the stem into coloured water. The colour of the blossom should be split after a day or two.**

Explore

COLLECT DATA FROM EXPERIMENTS

The students are asked to think up their own experiment that might demonstrate the transportation of water in plants. The students can use the Internet or available literature for research, or discuss the matter with the teacher. This task can also be used as homework. In-class colouring of plants works best with pieces of celery about 1–2 cm wide. Put them in a thin layer of coloured water and watch the liquid rise in about 15 minutes.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

The two main processes for water transportation in plants are diffusion and osmosis. Water moves through vascular bundles and its transport relates mostly to its physical properties. Water mostly transports minerals from the soil (in our case, the colouring).

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

A discussion about similar processes in everyday life: capillary action in walls, clothing, the absorbency of paper towels, etc. A microscopic observation of appropriately stained and prepared vascular bundles is also possible. How many times can the stem be split? What about 'rainbow roses'?

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The students' experiments are evaluated by other students through peer review and by the teacher through a guided discussion.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The teacher tells a story of how he or she couldn't decide whether to wear a red or blue flower in his lapel to a formal event, so they decided to have a flower with both of these colors at once. The teacher then demonstrates the bi-colored flower and asks the students how is it possible.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: the teacher shows the class the double-coloured flower.

Demonstrated enquiry (level 0): the teacher asks how it is possible and then shows the class the inside of an opaque vase. The flower's stem was cut in half and each half was placed in a vial containing coloured ink. The teacher explains their hypothesis: that the flower somehow 'drank' the colour using the 'straws' in its stem. Students record this thought on their hypothesiser lifeline worksheet.

Structured enquiry (level 1): students then use their hypothesiser lifeline sheet to record their own alternative ideas about how the flower transports water and to record their tests and conclusions regarding these other explanations.

Solving the mystery: students are led towards the explanation of the mystery using ideas about water transport in plants and evaporation as a driving force to pull water upwards from the roots.

Resources

The colouration process takes a long time. You can watch it sped up with two white roses on the TEMI Youtube Channel:

www.goo.gl/tUDaq5
playlist > Colored flower

You can see the split colouration of a carnation on the TEMI Youtube Channel:

www.goo.gl/tUDaq5
playlist > Colored changing carnation

Red or blue flowers?

STUDENT WORKSHEET

The teacher couldn't decide whether to wear a red flower or a blue one, so they decided on a compromise! But something like that cannot be natural, can it?

Engage

WHAT'S INTERESTING?

Task: The teacher has an unusual flower to show: each half is a different colour. How can this happen?

Explore

WHAT'S HAPPENING?

Task 1: How do you colour a flower? How do you make it two different colours? It's all just one part of a greater mystery. If water always runs downhill, then how does it get UP into flowers?

Task 2: Even if water can get into flowers, what about big trees? How can they be strong enough to pull water up tens of metres?

Explain

WHAT'S CAUSING IT?

Task 1: You have learnt about diffusion and osmosis. Explain what these processes are and how they keep the plants hydrated.

Task 2: Mix the two coloured inks together. Why does the flower keep the separate colours instead of blending them?

Extend

WHAT'S SIMILAR?

Task: Lots of objects in everyday life have the same ability to 'pull' water as plants. Try experimenting with various materials. What do the ones that 'work' have in common?

Evaluate

WHAT'S MY UNDERSTANDING?

Task 1: Could you produce a flower with more than two colours? What would happen if you tried this process on a coloured flower instead of a white one? Could you produce a fabled blue rose?

Task 2: What did you learn about your clothes? Which fabric would be better in summer: one that 'pulls' water in or one that doesn't?

The leaking bag

What's the mystery?

Two beakers will be displayed at the front of the room. Both look identical in that they both contain a plastic zip-lock bag with a starch solution inside. The zip-lock bag is in a clear solution. What the students don't know is that while the solution in one beaker is just water, the second beaker contains iodine.

In beaker two, the colour of the starch inside the zip-lock bag will change. Students need to figure out why this is happening.

DOMAIN(S)

Biology.

SUBDOMAIN KEYWORDS

Diffusion and osmosis.

AGE GROUP

16 to **17** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation: **20 min**.

Approximate time in classroom: one **40 min**. lesson.

SAFETY/SUPERVISION

Normal lab safety precautions apply. Care should be taken when using glassware.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» Starch solution x 2
» Iodine, zip-lock bag x 2
» Beaker x 2
» Distilled water
» Examples of impermeable (glass tiles), permeable (coffee/tea filters), semi-permeable (Visking tubing) membranes
» Concentrated solutions (e.g. sugar solutions).

LEARNING OBJECTIVES

Students will learn about osmosis and different types of membranes.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher half fills two plastic zip-lock bags with a starch solution. The class will agree that the bag does not allow any solution to leak out. These bags will then be placed in two beakers, both of which contain a clear substance. What the students don't know is that one of the beakers has an iodine solution in it. When placed in the iodine, a colour change will occur. A blue-black colour will spread out inside the bag. Students are asked to record what they observe.

Explore

COLLECT DATA FROM EXPERIMENTS

Why does one beaker change colour while the other doesn't?

What do we know about starch and a blue-black colour?

Why did the iodine move into the bag and why didn't the starch move out?

How did the iodine pass through the bag if the starch and water did not?

What would happen if we used different types of bags/membranes?

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

The bag does not allow water or starch molecules to pass through. However, the iodine molecules are small enough to pass through the tiny pores in the bag. This activity may be used to describe a semi-permeable membrane as well as the effect of diffusion (the iodine will diffuse throughout the starch solution). It does not describe the action of osmosis, as water molecules are not allowed to move through the semi-permeable membrane. This will be explored in the extend section.

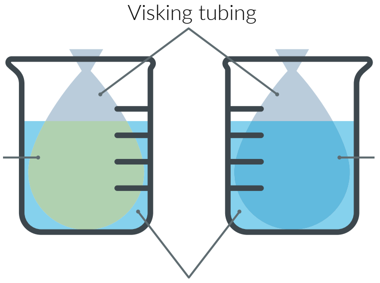
Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

The teacher informs the students that some membranes allow the movement of all molecules, some membranes don't allow the movement of any molecules, and some allow movement of a few molecules. This depends on the size of the molecules.

The students are informed that they must test the three membranes provided (Visking tubing, tea/coffee filters, and glass tiles). All they know is that one is permeable, one isn't, and that one is semi-permeable. The students work in groups of three to devise an experiment that shows the movement of concentrated substances across the three different membranes.

The pupils must recap the difference between high concentrations and low concentrations.



Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The teacher informs students that this movement of water is called osmosis and that some membranes allow osmosis to occur while others don't. The students should describe in their own words, or by using a diagram, how osmosis works by the movement of molecules from an area of high concentration to one of low concentration. Can you think of any other examples where osmosis is important in our lives? Do plants use osmosis in any way?

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The teacher should present the demonstration to the students by using the zip-lock bags and iodine. As the students will understand the effect of iodine on a starch solution, they may be able to discuss what has happened; however, they will question how the iodine was able to travel through the bag. The focus in this lesson is why certain molecules can move but not others. The students can use different membranes in their experiments to compare permeable, impermeable, and semi-permeable membranes.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: ask the students what happens when you spray perfume in a room. What happens over time? Does the smell travel?

Demonstrated enquiry (level 0): teacher-as-model. You show how to carry out an enquiry process which students then copy, explaining your hypothesis and tests by 'talking aloud'. Students record your thinking on their hypothesiser lifeline sheet.

Structured enquiry (level 1): 'we do it'. Students then use their hypothesiser lifeline sheet to record alternative ideas about why the iodine solution was able to travel through the zip-lock bag and to note down their tests and conclusions about other possible explanations.

Solving the mystery: students are led to the explanation by using ideas about the structure of the membrane.

The leaking bag

STUDENT WORKSHEET

You have just seen two plastic zip-lock bags with a starch solution placed in beakers. When we placed the starch solution in the beaker, a colour change occurred in one beaker. Why did this happen? How did the iodine pass through the bag if the starch and water could not? Discuss in your group how the iodine was able to pass through the bag and list your ideas. Finally, test each possibility and deduce what happened.

Engage

WHAT'S INTERESTING?

Task: Observe the demonstration and note any observations you may have.

Explore

WHAT'S HAPPENING?

Task: Why does one beaker change colour while the other doesn't?

What do we know about starch and a blue-black colour?

Why did the iodine move into the bag and why didn't the starch move out?

How did the iodine pass through the bag if the starch and water did not?

What would happen if we used different types of bags/membranes?

Explain

WHAT'S CAUSING IT?

Task: The bag does not allow water or starch molecules to pass through. However, the iodine molecules are small enough to pass through the tiny pores in the bag. Other membranes would allow bigger molecules to pass through. Let's explore the different types of membranes you can use.

Extend

WHAT'S SIMILAR?

Task: An experiment to 'investigate the direction of water molecules' movement across different types of membrane between two solutions of different concentrations'.

Having discussed the design of the experiment with the teacher, conduct the experiment and record your observations

What is meant by a high- and low-concentration solution?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Describe, in your own words or by using a diagram, how osmosis works. Where can we see the effects of osmosis in the real world? What happens to your fingers and toes when you have a bath? How could this 'pruning' be an example of osmosis? How do plants get water and nutrients from the soil?

Why did mammoths become extinct?

What's the mystery?

Why did mammoths become extinct? Scientists have presented two claims: climate change or human hunters. In this lesson students apply their knowledge of evolution and study evidence to decide which claim is best supported.

DOMAIN(S)

Biology.

SUBDOMAIN KEYWORDS

Adaptation, extinction, natural selection, climate.

AGE GROUP

11 to **14** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
20 min.

Approximate time in classroom:
one 50 min. lessons.

SAFETY/SUPERVISION

Normal classroom supervision.

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PREPARATION AND LIST OF MATERIALS

» Arrange colour print outs of student sheets 1-5 around the room.

» Provide each student with their own copy of the Construction Explanations Lifeline.

LEARNING OBJECTIVES

Critique claims: Use evidence to support or refute claims for why mammoths became extinct.

Evolution: Explain how a change in the environment can leave a species less well adapted which may lead to extinction.

Guidance notes for teachers

THE 5E MODEL

Please refer to the slide presentation "Why did mammoths become extinct" on the TEMI slideshare page www.slideshare.net/temiEC/

Engage

CAPTURE STUDENTS' ATTENTION

Slide 2: Display the mystery question 'Why did mammoths become extinct'? If you wish you can show students a video clip to show the efforts gone to by a film crew to recreate a mammoth (see the Resources section below).

Slide 3: Ask students to discuss their ideas about why mammoths may have become extinct.

Slide 4: Show the objectives.

Explore

COLLECT DATA FROM EXPERIMENTS

Slide 5: Introduce the two claims the students will be studying.

Slide 6: Organise students into small groups and provide each with a "Construct explanations lifeline". Ask the students to circulate round a 'conference' to gather evidence from scientists. Students complete the Lifeline using the evidence. Students should complete the final column after EACH piece of evidence to explore how they decide which claim is more probable. Reassure students that there is no 'right' answer. What is important is that students within their group discuss and evaluate which claim seems more probable at that point and recognises when they do and do not change their view on this.

Ask each group of students to talk through their Lifeline. Ask questions about how students decided which claim they supported overall, if they had changed their mind at any point and why.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Slide 7: Scientists have been analysing data relating to how many large mammals became extinct in different areas of the world. Allow pairs to study the map. Explain the correlation (or lack of) between the extinction map and the temperature change map. Students should notice that whilst an area such as North America showed a high level of extinction and significant temperature change the same cannot be said of South America. This casts doubts upon the climate change claim.

Slide 8: Ask students to consider the second map. Explain that this shows how man gradually spread across the world. Earliest man (e.g. Homo erectus) lived in Africa whereas the first humans to reach North and South America were modern humans Homo sapiens). There seems to be a correlation between high levels of extinction and areas of the world where the first human species to arrive was modern man.

Slide 9: Explain the science behind the human hunters claim. Discuss how animals may be adapted to avoid becoming prey to a predator. Ask how human hunters were different to the predators that mammoths were used to. What advantages may modern man have had that could have led to much higher levels of extinction? Why might more mammals have survived where they were used to living with early man?

Slide 10: Explain the science behind the climate change claim. Discuss how a change in climate can affect the environment. Make sure students understand that it is not simply a matter of an increase in temperature or ice melting. Plant life and animal life changes which means that the food supply for the mammoths may have changed. As animals are adapted for a specific environment a lack of an ability to adapt can lead to extinction.

Slide 11: Explain to students that unfortunately we do not yet know the answer to this mystery as scientists still cannot agree. Further studies have added evidence for each claim. Emphasise to students that this is an ongoing area of scientific research. Eventually scientists may reach a consensus.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Slide 12: Inform the students that the blue whale is at risk of extinction.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Ask pairs to discuss possible reasons why the blue whale is at risk of extinction.

After listening to their ideas discuss that human hunting was almost stopped by the introduction of a ban on whale hunting. However, climate change is now a big threat. The warming of the oceans is reducing the krill population on which the blue whale feeds.

Humans are still a threat to the survival of the blue whale for other reasons such as toxic materials in the ocean, ship strikes and being tangled in fishing nets.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Use the film clip to engage students and ask the question 'Why did mammoths become extinct?'

An optional extra is to discuss the question 'If scientists did clone a mammoth how could they ensure that the mammoths survived this time? What would scientists need to know?'

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Demonstrated Enquiry (Level 0): Teacher as model, you use the 'Critique Claims Lifeline' to work through the example, which shows how to judge two possible explanations - claims - for an observation. The one which best explains the evidence is the one we should accept.

Structured Enquiry (Level 1): 'We do it', students complete their Lifeline independently as they circulate around the mammoths conference and read about the evidence for different claims. They discuss which claim is best supported by the evidence overall.

Solving the mystery: Following the revealing of the latest research students are led towards an explanation of the mystery as to which claim for the extinction of mammoths is best supported the evidence.

Resources

Look for the slide presentation **"Why did mammoths become extinct"** on the TEMI slideshare page www.slideshare.net/temiEC/

Mammoths recreated:
http://entertainthis.usatoday.com/2015/02/11/watch-awesome-woolly-mammoths-come-to-life-in-this-exclusive-game-of-thrones-clip/

Why did mammoths become extinct?

STUDENT WORKSHEET

Thousands of different species that once lived on Earth no longer exist - they are extinct. One example is the mammoth which died out around 3600 years ago. Scientists are unsure what happened.

Can you solve the mystery: Why did mammoths become extinct?

Engage

WHAT'S INTERESTING?

Task: Discuss with a partner why you think mammoths may have become extinct. Arrange your theories in order from the most likely to the least likely.

Explore

WHAT'S HAPPENING?

Task 1: Walk around to each conference table and read the information from the scientists (Slides 1-5). For each scientists complete one row of your Lifeline.

Task 2: Discuss the last column with your group and try to agree which claim you think is most probable based on the evidence so far.

Task 3: Now read the latest research provided by your teacher. Add this to your Lifeline. Do you change your mind on which claim is more probable?

Explain

WHAT'S CAUSING IT?

Task: Read the information.

Prey animals are adapted to escape. The arrival of man introduced a new predator. If mammoths were not able to adapt then the numbers of mammoths killed would have increased and this could have led to their extinction.

Climate change resulted in a change in the mammoth's habitat from grassland to forests. If mammoths were unable to adapt to this new diet then this could also have led to their extinction.

Scientists are collecting more evidence all the time. Some recent evidence suggests that human hunting may have been to blame but not all scientists agree.

Extend

WHAT'S SIMILAR?

Task: The largest living mammal today, the blue whale, is threatened with extinction. What does this mean?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Research the answers to the following questions:

a) What has caused this fall in the blue whale population over history?

b) What is still a threat?

Chemical garden

What's the mystery?

The chemical garden is a well-established experiment from the chemistry of salts, solubility, diffusion, and solutions. The nice thing is that if metal salts are put in sodium water glass solution, it can lead to an effect reminiscent of plants growing. This growing process can be observed and analysed. In the end, the experiment looks like a wild garden.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Salts, crystals, solubility, diffusion, membranes, sodium silicates, osmosis.

AGE GROUP

12 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
15 min.

Approximate time in classroom:
90 min. lessons.

SAFETY/SUPERVISION

Lab coat and safety goggles.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Sodium water glass solution
- Iron(III)chloride
- Copper(II)sulphate
- Copper(I)chloride
- Calcium chloride dihydrate
- Potassium permanganate
- Water
- Sand
- Plastic beakers (20 ml and 200 ml)
- Glass beakers (200 ml)
- Glass rod
- Test tubes
- Test tube rack
- Test tube holder
- Heating plate
- Graduated cylinders (10 ml and 25 ml)
- Spatula
- Thermometer
- Magnifying glass
- Microscope
- Petri dishes

LEARNING OBJECTIVES

Students will learn about salts, solubility, semi-permeable membranes, diffusion, and osmosis.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher presents a ready-'grown' chemical garden. The students can start to 'grow' their own gardens in very small plastic beakers. They can make observations about the growing crystals, and raise questions about the crystal growth and the nature of the mysterious solution. Questions might concern the phenomenon in general, differences in the behaviours of various salts, factors influencing the growth, or the composition and behaviour of the generally unknown water glass solution.

Explore

COLLECT DATA FROM EXPERIMENTS

The students enquire into the mysterious behaviour of the metal salt crystals when put into the water glass solution. They explore the process and the resulting structures. Factors that might be investigated concern the behaviours of different sorts of metal salt, different temperatures, or varying concentrations of the water glass solution. A central experiment is using a colourless salt and a water glass solution coloured by ink; the resulting structures and membranes are then observed with a magnifying glass or a microscope.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Water glass is a barely soluble membrane made of certain metal cations on the surfaces of the crystals. The membrane is semi-permeable. Water passes through the membrane while the metal ions do not. Water enters the membrane mantle because of osmotic pressure. Water dissolves further ions from the crystal. As water passes through the membrane, the pressure inside the mantle constantly increases. At a certain point, the mantle cracks and a new membrane is formed. This mainly happens on the top of the mantle because of a gradient in density. Constant repetition of this effect leads to a growth in the structure.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

The task can be extended by reflecting on the potential technical applications of sodium water glass (e.g. in house building). After drying, sodium water glass forms a hydrophobic coating that can be used to seal porous surfaces. Students can also learn about the different structures and the uses of silicates.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

An experiment about another semi-permeable membrane (cellophane) can be used to assess whether students are able to apply their new knowledge to another example. The cellophane film in this case acts as a membrane. As with the chemical garden, this is permeable to water. Solved substances like sugar cannot pass the membrane, just as the metal salt ions cannot do so in the chemical garden experiment.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

This mystery can be carried out without further aids as a demonstration experiment. It should be ensured that the students can observe the experiment closely. Since the crystals are very small, the students must be close to the experiment in order to observe it. The teacher leads the demonstration in silence without further impulse or comment. The experiment is so fascinating to the students that they begin to question the phenomenon automatically.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The mystery is presented as a guided enquiry (level 2). Students should investigate the structures formed by the metal salt crystals in the water glass solution. They may investigate the behaviour of solutions with different concentrations, at various temperatures, or with different sizes of crystal. The students can make their own plans about how to do the experiments. Observations must be collected and organised in order to explain the phenomenon.

Solving the mystery: the most helpful evidence for finding the explanation is working order no. 4. Once the students have dyed the crystal, they can identify that the silicate mantle acts as semi-permeable membrane. One sees that there must be a membrane, as this has been coloured from outside to the core. However, the original crystal retains its initial colour.

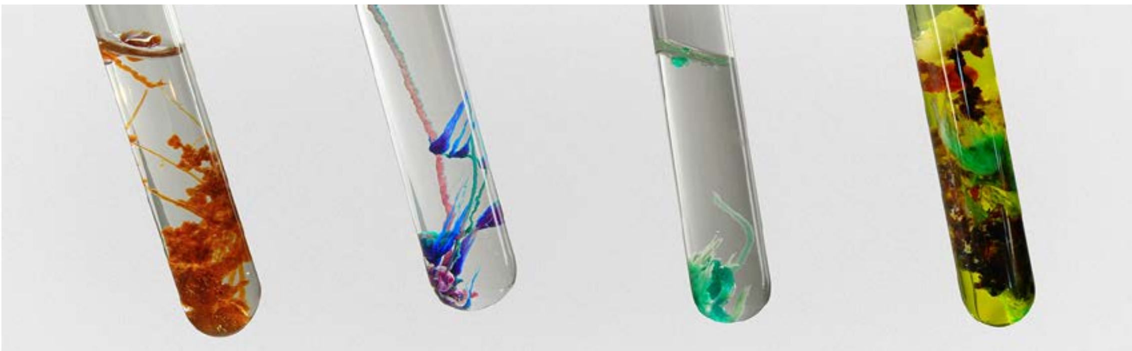
Resources

Brandl, H. (1998). Trickkiste Chemie. Bayerischer Schulbuch Verlag, München.

Chemical garden

STUDENT WORKSHEET

Nature offers a lot of fascinating phenomena, like beautiful flowers and picturesque gardens. However, living organisms die off as time passes. Flowers shrivel, leaves lose their colour, and, finally, only the memory remains. Chemistry offers an alternative. Chemists know how to create artificial and everlasting gardens. How do they do so? How do chemists 'grow' a chemical garden like the ones in the picture below?



Engage

WHAT'S INTERESTING?

Task: Take one of the small plastic beakers (0.02 ml). Add some water glass solution. Add small crystals of iron(III) chloride, copper(I)chloride, or sodium permanganate.

Describe your observations and suggest questions.

Explore

WHAT'S HAPPENING?

Task 1: Explore the behaviour of the iron(III) chloride crystals in the sodium water glass solution. Investigate the resulting structures with a magnifying glass or a microscope. Describe your observations and suggest an explanation of the observed effects.

Task 2: Explore the behaviour of different metal salts in sodium water glass solutions with different concentrations. You might take iron(III)chloride, copper(II)sulphate, and calcium chloride dihydrate. Describe your observations and suggest an explanation of the observed effects.

Task 3: Explore the behaviour of iron(III)chloride in the sodium water glass solution at various temperatures and with crystals of differing degrees of fragmentation. Describe your observations and suggest an explanation of the observed effects.

Task 4: Explore the behaviour of colourless metal salts in a sodium water glass solution coloured with blue ink. Describe your observations and suggest an explanation of the observed effects.

Explain
WHAT'S CAUSING IT?

Task 1: Draw pictures of the different observations.

Task 2: Develop a table to categorise all your observations from the different experiments.

Task 3: Explain how and why the crystals in the chemical garden grow. You can search the Internet for further explanations. You may search for topics like crystals, solubility, and the function of semi-permeable membranes.

Extend
WHAT'S SIMILAR?

Task: Conduct the following experiment and explain how sodium water glass can be used in construction.

Materials:
Sodium water glass solution, vinegar essence, water, clinker, limestone, paintbrush, hair dryer.

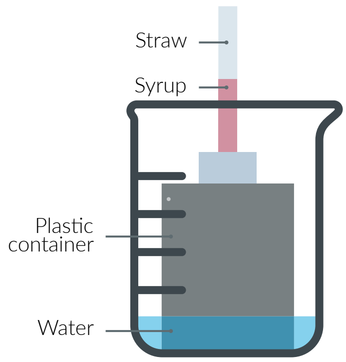
Procedure:
1. Paint half of the surface of the clinker and the limestone with the water glass solution.
2. Dry with the hair dryer.
3. Sprinkle the whole clinker with water.
4. Sprinkle the whole limestone with vinegar essence.
5. Describe your observation and explain.

Source: Kober, F. (1984). Struktur der Silicate. Der Chemieunterricht, 3/5, 21.

Evaluate
WHAT'S MY UNDERSTANDING?

Task: Conduct the following experiment and explain how this experiment is connected to understanding the chemical garden.

1. Take a small plastic container with a waterproof cap. Drill holes into the bottom and into the cap.
2. Take off the cap. Put a piece of cellophane foil over the container and fix it on the cap.
3. Turn the container around. Put syrup in through the hole in the bottom.
4. Fix a straw through the hole at the bottom either with a pierced stopper or plasticine.
5. Place the container bottom-up in a beaker containing some water.
6. Describe and explain your observation.



CHEMISTRY

The Book of Science Mysteries

Chemical seesaw

What's the mystery?

A balance is set up with two pieces of iron wool. One piece is set alight: it appears to be getting smaller but, mysteriously, the balance tips the other way.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Chemical reactions, particles, conservation of mass, oxidation.

AGE GROUP

11 to **14** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation: **45 min.**

Approximate time in classroom: **One 50 min. lesson.**

SAFETY/SUPERVISION

Be careful when burning the materials in the classroom. Use eye protection.

PREPARATION AND LIST OF MATERIALS

For teacher demonstrations:

- Simple balance (for instructions, see the Resources section).
- Four aluminium trays (two can be stuck on top of the metre ruler). When burning the paper, place two more trays on top and remove these so you have clean trays to burn the iron wool.
- Two pieces of screwed-up paper of equal mass
- Two pieces of iron wool of equal mass. Clean these in acetone first to remove any grease.
- Bunsen burner
- Wooden splint
- Two pieces of magnesium strip
- Tongs
- Gas jar of pure oxygen
- Optional:
- Piece of carbon (charcoal)
- Deflagrating spoon

LEARNING OBJECTIVES

Students will construct explanations using particles to demonstrate what happens during a chemical reaction.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Add small pieces of screwed-up paper of equal mass to each tray so that they balance. Use a burning splint to set one piece of paper alight. Quickly ask the students to predict what they think will happen to this side of the balance: will it go up or down? You should see that the metal tray goes up as the mass of the paper decreases. Repeat this process, but use two pieces of iron wool of the same mass. Again, ask the students to predict what they think will happen. This time they will see that the tray with the burning iron wool goes down as the iron gets heavier.

Explore

COLLECT DATA FROM EXPERIMENTS

Explore 1: students are guided on how to use the construct explanations lifeline. They see the reaction of magnesium burning in air and are shown how to work out the chemical reaction taking place.

Explore 2: students use the lifeline to write their explanation as to why the mass of iron increased when it was burnt in air.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Use particle diagrams to show that oxygen joins with the iron atoms to produce a product called iron oxide. As it contains oxygen atoms, iron oxide has a greater mass than iron atoms. NB: iron oxide has the formula $\mathbf{Fe_2O_3}$, so each iron atom doesn't join with one oxygen atom like it does when forming magnesium oxide. You may wish to discuss this with some classes, depending on how much work they have done on chemical formulae.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Students are asked what they think will happen to the mass of a lump of carbon as it is burnt.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students write down what they think will happen and why. You can use this output to assess student understanding.

You may wish to demonstrate the reaction to show that the lump of carbon will get smaller. This is because the gas carbon dioxide is produced, which is then lost to the air.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The engage part of the lesson shows a discrepant event: students will see the mass of the paper decreasing and assume it will be the same when iron burns. Use this to add surprise and intrigue to the lesson so that students are motivated to find out why this happened.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Demonstrated enquiry (level 0): this takes place during explore 1. The teacher goes through how to use the construct explanations lifeline in order to explain the chemical reaction that occurs when magnesium burns.

Each step is explained:

» Write down your observations.

» Recall any relevant science ideas.

» Connect idea to observation.

» Does this idea help to explain your observation?

» Write a clear and organised explanation.

Structured enquiry (level 1): this takes place during explore 2. The students work without the teacher’s guidance to explain why the mass of iron increased when it was burnt in air. They use the lifeline and the guidance they received during explore 1 to do this.

Solving the mystery: students are led towards the explanation by using ideas about how atoms are rearranged during chemical reactions.

Resources

Instructions on how to build the balance equipment:

www.nuffieldfoundation.org/practical-physics/simple-balance-2

Chemical seesaw

STUDENT WORKSHEET

What happens when a substance burns? Burn a piece of paper and it gets smaller and smaller: its mass decreases. But where does all this lost mass go?

Do all substances lose mass when they are burnt?

Engage
WHAT'S INTERESTING?

Task 1: Watch the chemical seesaw. What happens to the mass of iron when it is burnt?

Task 2: Was this what you were expecting? Why?

Explore
WHAT'S HAPPENING?

Task 1: Your teacher will burn another metal, called magnesium, in air.
Write down your observations.

Task 2: What evidence is there that a chemical reaction is happening?

Task 3: What scientific ideas do you know that could explain what is happening in this chemical reaction?

Task 4: Write down the explanation your teacher gives you.

Task 5: Use the construct explanations lifeline to help you explain why the mass of iron increases when it is burnt.

Explain
WHAT'S CAUSING IT?

Task: Your teacher will explain why the mass of iron increases when it is burnt. Is your explanation correct? If not, improve it.

Extend
WHAT'S SIMILAR?

Task: Carbon is an element, so it only contains carbon atoms. Think about the chemical reaction that happens when it burns in air.

Evaluate
WHAT'S MY UNDERSTANDING?

Task: Conduct the following experiment and explain how this experiment is connected to understanding the

Eating nails

What's the mystery?

Are we really eating nails? How can there be iron in our cereal? The mystery here is the teacher demonstrating that iron filings can be extracted from a sample of breakfast cereal.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Elements, compounds, mixtures.

AGE GROUP

12 to **15** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
15 min.

Approximate time in classroom:
80 min.

SAFETY/SUPERVISION

Food used in any lab experiment is not to be eaten.

Care should be taken when using food blender: ensure the blender is switched off at the wall until it is properly set up and ensure the lid is on before blending.

Care is to be taken when handling hot glassware: use tongs or heat-resistant gloves.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

For a teacher-engaged demonstration:

- Blender
- Breakfast cereal containing added iron
- Strong magnet
- Projector (if available)

For a student-explore activity:

- Beaker
- Strong magnet
- Mass balance
- Weigh boats
- Spatula
- Test tube
- Tongs
- Bunsen burner
- Pestle and mortar
- Iron filings
- Sulphur
- 1.0M HCl

Notes:
Some materials can be found at home (food blender).

Neodymium magnets are more effective if they are available. These can be sourced from science education equipment suppliers. Care is required when handling these powerful magnets.

LEARNING OBJECTIVES

- Students will learn about the properties of elements (e.g. iron).
- Students will understand the difference between a mixture and compound.
- Students will test and observe the properties of a mixture and a compound.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Would you believe me if I were to tell you that I can make the invisible visible?

» Teacher tells the class that he/she is able to separate a particular ingredient in the cereal and make it visible with a 'magic wand' (magnet).

» The teacher will blend two cups of cereal with water. The teacher will let the mixture sit for two minutes and then stir with a very strong magnet (neodymium magnet if available). A projector could be used to show the demonstration clearly.

» The students will be amazed to observe tiny grey particles on the magnet.

Explore

COLLECT DATA FROM EXPERIMENTS

How does our body digest this iron?

Do you think this iron will travel through the intestinal tract as an iron nail would?

» Brainstorm ideas about how the body digests this iron.

» Add 10 ml of 1.0M HCl to 100 ml of the cereal slurry to simulate stomach acid. Heat in a beaker of hot water.

» After the addition of HCl, the acid oxidises the elemental iron to iron(III) ions, which are not as attracted to a magnet. The addition of NaSCN (sodium thiocyanate) solution should turn the slurry red, thus confirming the presence of these iron ions.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

» Several breakfast cereals contain iron as a mineral supplement. The iron is in the form of iron powder and can be extracted from a suspension of crushed cereal in water by using a magnet. This discrepant event is intended to show that breakfast cereals are a mixture of various substances that are mingled together but not chemically combined.

» The stomach contains a strong acid, hydrochloric acid, that can break down the iron into iron(III) form (ferric). This is then broken down further before being absorbed into the blood stream. It is then used to transport oxygen around the body.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Comparison of mixtures and compounds (1): Students have to prepare their own mixture and compound samples using the materials and equipment provided.

On completing the investigation, the students should be able to determine the different properties of a mixture and a compound:

» Mixture of iron and sulphur. The iron can still be separated with a magnet (the element retains its property).

» Compound of iron and sulphur. The mixture is heated to form iron sulphide. The iron can no longer be separated by a magnet (the compound has new properties).

Comparison of mixtures and compounds (2): Students can be provided with different colour plastic building blocks (e.g. Lego). Each colour represents a different element. The students can use these to make concrete representations of the mixture (e.g. two or more different colour blocks not joined together) or a compound (e.g. two or more different colour blocks joined together).

Real-life application
Iron is an essential mineral. It is found in haemoglobin in red blood cells. It is needed for the transportation of oxygen from the lungs around the body. If the body does not have enough iron, it cannot make enough oxygen-carrying red blood cells. This deficiency is called anaemia.

Healthy red blood cells and sufficient oxygen is important to prevent fatigue. Athletes need sufficient oxygen supply in their blood and muscles to maximise their performance and prevent fatigue. Blood doping is a method of increasing the number of red blood cells in the body. This allows more oxygen to be carried to the muscles.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students should know:

» Elements in a mixture retain their properties: elements do not retain their own properties when in a compound.

» There is a chemical change when a mixture is formed into a compound.

» This conservation of properties may often be used to separate components in a mixture.

Students should be able to:

» Explain why it is possible to ingest table salt (NaCl), even though the two elemental components are highly reactive and poisonous. From the experimental investigation with iron and sulphur, students should know that compounds have new properties: the elements do not retain their own properties.

» Carry out an investigation on the iron levels in different cereals and compare the results with the levels shown on the cereal packet labels.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

When extracting the iron from the cereal with the 'magic wand', it is important not to tell the students what they should expect. All the students should know is that the teacher thinks it is possible to make the invisible visible. Allow the students to observe what is extracted from the cereal for themselves.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Students will learn about the following skills through the GRR model:

» Separating techniques.

» Experimental work.

» Predict, observe, and explain procedures.

» Project and group work.

Resources

There are a number of YouTube videos showing how to extract iron from breakfast cereal.
On the TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > Extracting iron from cereals

There are also many videos on You Tube about the various ways in which teachers can introduce the concepts of elements, compounds, and mixtures to students. On the TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > Building models of elements, compounds and mixtures

An additional short documentary-style video can be viewed on how blood doping works.
On the TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > Blood doping

Eating nails

STUDENT WORKSHEET

You have seen how your teacher separated a previously 'invisible' ingredient from breakfast cereal.
What was this ingredient called?
How was the teacher able to remove this ingredient from the cereal?
Why were the other ingredients not attracted to the 'magic wand'?
You should investigate this observation and the properties of the ingredient using the materials provided.

Engage

WHAT'S INTERESTING?

Task 1: If this grey ingredient is in the breakfast cereal, why do we not see it or at least feel it when we bite into the cereal?

Task 2: Do you think our cereal could rust if it's left out long enough?

Task 3: Iron is often added to foods such as breakfast cereals. Why do we need iron in our diet?

Task 4: From what you have learnt about iron in the diet, what group of people usually require iron the most and why?

Task 5: Is the breakfast cereal used in the first demonstration an example of a mixture or a compound? Explain your reasoning.

Explore

WHAT'S HAPPENING?

Task: How does our body digest the iron from breakfast cereal? Would it be possible to digest an iron nail?

Teacher Demonstration:
Help your teacher to design an experiment to show how our bodies digest the iron from food, such as breakfast cereals.

Explain

WHAT'S CAUSING IT?

Task: Several breakfast cereals contain iron as a mineral supplement. The iron is in the form of iron powder and can be extracted from a suspension of crushed cereal in water using a magnet. This discrepant event is intended to show that breakfast cereals are a mixture of various substances that are mingled together but not chemically combined.

The stomach contains a strong acid, hydrochloric acid, that can break down the elemental iron into an iron(III) form (ferric). This is then broken down further before being absorbed into the blood stream. It is then used to transport oxygen around the body.

Extend

WHAT'S SIMILAR?

Task: **Compare a mixture of iron and sulphur to the compound iron sulphide.**
How you will do it...

Using a pestle and mortar, grind up a mixture containing 6g of iron and 4g of sulphur.

Wrap a magnet in paper and bring the magnet close to the mixture. What happens? Record your results.

Remix the iron and sulphur using a spatula and place the mixture in a test tube.

Heat the test tube until the mixture glows red (**this is to be done in a fume cupboard with teacher supervision).

Continue heating until the mixture stops glowing.

Allow the test tube to cool. Wait until your teacher has visited your station and then carefully remove the grey solid that has been formed for closer examination.

Bring a magnet close to the grey solid. What do you notice? Record your observations

Activity

Use the coloured Lego blocks to represent various elements, compounds, and mixtures.

Evaluate

WHAT'S MY UNDERSTANDING?

Task 1: What is the difference between an element, a compound, and a mixture?

Task 2: Table salt is made up of a very reactive metal and a poisonous green gas. Can you name these two elements? Briefly explain why it is possible to ingest table salt even though it is made from these harmful elements?

Task 3: How could you compare the iron levels present in various breakfast cereals?

Task 4: Briefly explain how blood doping works.

Gelli Baff®

What's the mystery?

Sarah and Philip were taking a bath with Gelli Baff, a crystalline powder which is dumped into a bathtub filled with water. The viscous hydrogel was great fun. Now they want to drain the bathtub. How can they force the viscid stuff to go down the plughole?

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Superabsorbents, polymers.

AGE GROUP

On a submicroscopic level: **16** to **18** years old.

On a phenomenological level: **6** years **and older**.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
20 min.

Approximate time in classroom:
two individual **50 min.** lessons.

SAFETY/SUPERVISION

The superabsorbent can be used by kids. There are no safety restrictions or regulations except that the substance should not be eaten!

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Coloured superabsorbent for the bathtub (e.g. Gelli Baff)
- Nappies
- Uncoloured superabsorbent polymer
- Toothpastes
- Hair gels
- Crystal sugar
- Crystal soda
- Vinegar essence
- Lemon juice
- Citric acid
- Salt
- Sea salt
- Powdered sugar
- Plastic bowls
- Measuring glass
- Measuring container
- Porcelain cup
- Matches
- Spoons
- Stirrers, etc.

LEARNING OBJECTIVES

Students will learn about swelling reactions, balanced reactions, and polymerisation.

Students should be able to describe how a superabsorbent works and establish a relationship between superabsorbents and polymers. Students should be able to describe how the gel becomes liquid again. Students should realise the relationship between the absorption ability of the absorber and the salt concentration of the liquid.

Guidance notes for teachers

THE 5E MODEL

Engage
CAPTURE STUDENTS' ATTENTION

Tell the students the story about the two kids bathing in Gelli Baff. Make the story more personal if you like (maybe tell the students about your nephews or neighbours). It is recommended that you have a big beaker or transparent bowl filled with Gelli Baff. Put your hand in to show the students the consistency while you relate details about the viscous substance. It might also be interesting to put the powder into the water in front of the kids and let them see what happens.

Explore
COLLECT DATA FROM EXPERIMENTS

Students can try out the Gelli Baff on their own. For some, it will be a matter of trial and error. Make sure then that the trial is systematically organised (control of variables). The students have several different materials to work with. A material table is appropriate for this phase. You can design it with more or less material on it. The more material, the more complex the explore phase gets.

Perhaps you use an experiment with nappies beforehand to develop some knowledge about superabsorbents. Test the amount of tap water and salt water that can be absorbed by a nappy.

Explain
WHAT'S THE SCIENCE BEHIND THE MYSTERY?

The main ingredient is the sodium salt of polyacrylic acid. This has the chemical formula $[-CH_2-CH(CO_2Na)-]_n$ and has broad application in consumer products. Polyacrylic acid cross linkers can absorb about 1000g of water per gram polymer. Water molecules can group strongly around the ionic endings because the polymer can spread out. Hydrogen bridge links stabilise the structure. Adding sodium chloride balances the charges of the carboxylate group. The electrostatic repulsion decreases and the gel no longer absorbs water. The dispersed molecules enmesh again. Adding acidic substances causes the same effect.

With younger students, stay on the phenomenological level.

Extend
WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Superabsorbent polymers are also used in cosmetics like hair gel or some toothpastes. Students can experiment with these products and compare them with Gelli Baff.

Superabsorbents are also used in fire protection. Students can test whether or not Gelli Baff is flammable.

Students can also compare Gelli Baff with the contents of nappies and find out which of the super absorbers can hold more water. They can find out if there is a difference when using tap water, purified water, or water with 0.9 % sodium chloride (to simulate urine).

Students can figure out how super absorbents can be produced.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The students should now be able to figure out what the second powder (sodium chloride) in the package is and explain how the liquefaction reaction works.

After experimenting, the students can pick the best product (e.g. nappies) and describe why this product holds the largest amount of liquid. Using this knowledge, they can develop product adverts.

Older students can describe how polymerisation reactions run and how super absorbents are produced. Additionally, they can discuss whether Gelli Baff is a harmless and funny toy or a pollutive product.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The teacher can act out the story of Sarah and Philip, maybe together with two students acting the parts in the secret. They come into the 'bathroom' and want to have fun. The bathtub (a large plastic box or beaker) is already filled with water and the teacher adds the Gelli Baff powder.

Now he or she can 'bathe' and let the students feel the gel. When everyone who desires to do so has felt the gel, the teacher can ask a student to drain it. Now the "how" question has to be developed: this starts the exploration.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The mystery is a guided enquiry (level 2) where the students have to choose the method they use to liquefy the Gelli Baff. The enquiry skills they can develop with this mystery are planning and conducting experiments, recording observations systematically, giving priority to evidence, formulating explanations from evidence, and transferring knowledge to extended tasks.

Solving the mystery: by experimenting with different substances to liquefy the Gelli Baff, they discover the salt and acids as solutions to the task. Thus they are led, for example, to the reaction of polyacrylic acid and sodium chloride as well as to the mechanism of swelling reactions.

Resources

Look for the **"Forest fires, polymers, and the chemistry of nappies"** and **"Experimenting with FAVOR®-Superabsorbents"** on the TEMI Slideshare page **www.slideshare.net/temiEC/**

Gelli Baff®

STUDENT WORKSHEET

The mystery is about a coloured crystalline powder, which is dumped into a bathtub filled with water. The Gelli Baff turns into a viscous hydrogel, which is great fun!

The challenge starts after bathing: how can you get the viscous Gelli Baff to go down the drain?

Come up with a solution to the mystery.
Log your ideas, observations, procedures, and results in your exercise book.

Engage

WHAT'S INTERESTING?

Task: Sarah and Philip took a bath in Gelli Baff. They put the crystalline powder into the bathtub; with the water, it forms a colourful and viscid gel. It was a lot of fun to bathe in, but now it is time to drain the bathtub. How can they force this viscid substance to go through the plughole?

Explore

WHAT'S HAPPENING?

Task 1: Come up with different hypotheses for how you could initiate the liquefaction (i.e. how could you turn the Gelli Baff into a liquid?).

Task 2: Explore how you can make the Gelli Baff liquid. Use the materials provided: crystal sugar, crystal soda, vinegar essence, lemon juice, citric acid, salt, sea salt, and powdered sugar. Test the materials systematically.

Task 3: Try to find alternatives to Gelli Baff to create a similar bath.

Explain

WHAT'S CAUSING IT?

Task 1: Create an explanation for the balanced reaction that takes place.

Task 2: Explain the reaction of sodium salt of polyacrylic acid, the main component of the Gelli Baff, with the substance that makes it liquid.

Extend

WHAT'S SIMILAR?

Task 1: Super absorbent polymers are also used in cosmetics, such as hair gels or in some toothpastes. You can also explore whether these products behave in the same way as the Gelli Baff.

Task 2: Super absorbent polymers are also used in fire protection. You can test whether Gelli Baff is flammable.

Task 3: You can also compare Gelli Baff with nappies to find out which superabsorbent polymer can hold more water. Be sure to conduct your experiment using saltwater as well.

Task 4: Try to come up with a method of discovering what the mysterious second powder in the original Gelli Baff package is.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Design a product advert about a super absorbent polymer for nappies, cosmetics, or other products. Give reasons for why your product is the best on the market. Use your knowledge about polymers and balanced reactions.

The Book of Science Mysteries

Grit on the streets

What's the mystery?

A common misconception is that gritting the sidewalk causes the temperature to increase and thus melt the ice. However, it is actually the other way around. Adding salt to a water-ice mixture lowers the freezing point of the solution, causing the ice to become liquid even though the temperature is below 0°C. This is the reason why we put grit on the streets and one of the reasons why ice rarely forms in oceans in temperate climates.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Phase transitions, salt, water, freezing point, boiling point, condensation.

AGE GROUP

14 to **15** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
30 min.

Approximate time in classroom:
One hour.

SAFETY/SUPERVISION

Supervision is recommended.

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PREPARATION AND LIST OF MATERIALS

The night before: fill milk cartons with water and put them in the freezer.

Equipment:

» Hammer
» Towel
» Thermometer
» 1kg salt (NaCl)
» Large 400 ml beakers
» Butane burners
» Tripods
» Matches.

LEARNING OBJECTIVES

Revision of phase transitions and the concepts of condensation and chemical bonds. The students should have prior knowledge about the particle model before starting this activity.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher tells a story about how in winter, when it gets cold, we tend to put grit on roads and pavements so that they do not freeze and get icy. The teacher acts as if he/she is curious about what happens when we do this and asks the students whether they have ever wondered about this. The teacher presents ice lollies made of frozen water and drizzles salt on one of them. He or she then asks the students if they believe that the temperature of the ice lolly with the salt will increase or decrease, causing it to melt faster. The teacher then says that the class will look at some characteristics of salt water and conduct a few experiments.

The teacher also asks the students to discuss in pairs what actually happens to the particles in the water when it freezes as well as the different phases in which water and other substances can exist. He or she tells the students that they are going to find out more about the properties of substances and how they might change in different conditions. The aim here is to activate the students' prior knowledge about the particle model.

Explore

COLLECT DATA FROM EXPERIMENTS

The teacher tells the students to discuss and write down a Hypothesiser Lifeline for an experiment (presenting them with the hypothesiser lifeline) and to test if salt increases or decreases a mixture's freezing point and boiling point. In this section, we recommend that you explain/revise what happens to the particles in a substance when the freezing or boiling point is reached.

The students should also find out how cold the mixture can get by adding salt to the solution while measuring the temperature. At the end of the lesson, you can maintain the students' interest by making ice cream by putting a plastic bag filled with lemonade into the ice-salt solution.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Adding salt to the ice will lower the freezing point of the solution. This is the reason why we put grit on the streets and why the salt is inefficient when the temperature goes below 15°C. Some substances have the ability to lower or elevate their freezing or boiling point in a solution/mixture. Ask the students to think about this the next time they take their dog for a walk on a gritted icy street.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

We have now seen how the freezing point of a mixture can change if we add something to it. What happens to the boiling point? Is it the same as for water, 100°C? Why would it increase or decrease? Tell the students to test this and to try to sort out whether the salt becomes gaseous along with the water when the solution boils. Is it possible to make fresh water from salt water? How can you test this? Use the hypothesiser lifeline.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

During the experiment, a conversation between teacher and students can take place. In pairs, the students explain the hypothesis, present the observed results, and the credibility of the hypothesis while using academic argumentation. Possible questions for discussion between the students might be: what happens on a molecular level when we add salt to the water and why can this affect the boiling temperature of the now heavier solution? Several YouTube movies have good animations of this.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Curiosity is a key ingredient in this mystery. To attract more attention from the students, one could colour the ice-lollies with various colours. One could also present some fun facts about how much salt we actually use on gritting the streets and who came up with the idea. You could also ask the students to discuss why seawater freezes slower than freshwater. In the extend section, one could also involve crystal making and geology by letting the students make their own salt crystals.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

This mystery begins as a structured enquiry (level 1). The students will have to think critically to design an experiment with a few selected variables. The degree of independence increases in the extend section, where the students will have to explore whether it is possible to produce freshwater from saltwater. Using the Hypothesiser Lifeline throughout the mystery is recommended.

Resources

This web site explains why the oceans do not freeze and offers a classroom activity: www.education.com/science-fair/article/why-doesnt-the-ocean-freeze/

Read more about the desalination of salt water at this web page: http://adventure.howstuffworks.com/survival/wilderness/convert-salt-water1.htm

Grit on the streets

STUDENT WORKSHEET

You have now heard from your teacher that it is a good idea to put salt on an icy pavement to make the ice melt. Why do we actually do this? Does the temperature of the ice increase, thereby causing it to melt? In this mystery, you will design an experiment to see what happens to the temperature when we add salt to ice.

Engage

WHAT'S INTERESTING?

Task: Discuss with your group what you think happens with the temperature of the ice when we put grit on the streets in order to make the ice melt. Do you remember the temperature in which water freezes to ice and what happens to the water particles?

Explore

WHAT'S HAPPENING?

Task: Work together in pairs. Write a hypothesis using the hypothesiser lifeline about what you think will happen when you add salt to an ice mixture. Describe an experiment where you test your hypothesis.

Test your experiment.

How warm/cold does the mixture get when you add salt?

Explain

WHAT'S CAUSING IT?

Task: What happened to the temperature of the ice mixture when you added the salt? How does this relate to the concept of the freezing point? What happens to the weight of the solution when you add the salt?

Extend

WHAT'S SIMILAR?

Task: We have now seen how the freezing point of a mixture can change if we add something to it. However, what happens to the boiling point? Is it the same as for water (100°C)? Why would it increase or decrease? Discuss this with your group and write down your thoughts. Try boiling the salt water to see if the boiling point has changed.

Even though oceans cover 71 per cent of the Earth's surface, the world is running out of drinking water. Can you think of a way of turning salt water into fresh water?

Does the salt evaporate as well as the water?

Use the hypothesiser lifeline to design a new experiment to test this.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Discuss with your group:

Why did the ice and salt mixture remain in a liquid state, even though the temperature was below 0°C?

What happens with the salt and water molecules when salt water boils?

Write down two things you learnt from this mystery and one thing you would like to learn more about.

The Book of Science Mysteries

Mysterious eggs

What's the mystery?

This is a mystery that allows the students to make a hypothesis based on the old advice saying that a rotten egg floats when it is put into fresh water while a fresh egg sinks.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Density, Archimedes, buoyancy.

AGE GROUP

13 to **15** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
One hour.

Approximate time in classroom:
One hour.

SAFETY/SUPERVISION

If a burner is used, students must be supervised properly.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» Butane burners
» Tripod
» Measuring cylinder
» Weight
» Matches
» Salt
» Eggs
» Other variants are also possible.

LEARNING OBJECTIVES

Explain what density is and why something floats. Conduct experiments and find sources of error (science concept).

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher tells the following story to the students. A farmer is selling eggs at a market and he is demonstrating that his eggs are fresh by placing them in freshwater and the eggs sink. He is selling many eggs, so a farmer in the neighbouring market stall becomes envious. He challenges the farmer by claiming his eggs are rotten. As evidence, he takes one egg and puts it in a solution which he claims is pure water. The egg floats and the customers are worried they have been deceived. Who is deceiving whom?

Explore

COLLECT DATA FROM EXPERIMENTS

Students design their activity to test their hypothesis. Which of the farmers is cheating?

Formulate testable ideas. Possible examples include, but are not limited to, the following:

What is the reason or reasons for the different results? Are the liquids different or is it the egg? If the students believe that the composition of the water is different, how can this be measured? This mystery is all about density. Depending on the students' prior knowledge, guide them towards measuring volume and weight.

Some of the measurement may have a wide margin of error, so it might be necessary to repeat the experiments. Take care to discuss margin of error and the validity of the results.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Tell the students to describe their experiment so they can solve the quarrel between the farmers. Who is tricking whom? Discuss possible sources of error. Make sure students use scientific terminology. Did the envious farmer add salt to the water to make it denser, thus making the egg sink? Yes!

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Boats made of wood and steel float equally well. However, from the previous investigation, it should be clear that dense objects sink. How is it possible that a boat made of steel does not sink? Discuss or experiment with objects (e.g. model clay) to find out how this can be the case. Explain what happens (requires knowledge of the concept of buoyancy).

Let the students think about if it´s easier to swim in a lake than in the ocean and what it is that cause something to float. Is it the floating object or the medium it floats/sinks in?

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The students could write a report from the experiment explaining their findings with proper scientific terminology.

The teacher could also start group discussions debating the following questions: what is the difference between 'dense' and 'heavy'? Why is it easier to float in the ocean than in a lake? When inhaling while swimming, it is harder to dive. Why?

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Tell the story engagingly. You could put on a hat and bring a couple of eggs in a basket with you? The story may also be enacted with the help of another teacher or students. In order to increase engagement, emphasise the conflict between the two farmers.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

This enquiry is a guided enquiry (level 1), where the students make their own experiment based on the story told by the teacher. They also have to collect information about other materials where a phase change is evident due to temperature variations. These experiments can easily be fine-tuned to different levels of enquiry. The best performing students can be given a large degree of freedom when it comes to designing their own experiments, while others might need a concrete hypothesis to test.

Give the students an instruction on how to handle the butane burner safely before they start their experiments.

Resources

This website describes the principles of buoyancy: http://hyperphysics.phy-astr.gsu.edu/hbase/pbuoy.html

Mysterious eggs

STUDENT WORKSHEET

It is a well-known fact that fresh eggs sink in pure tap water, while rotten eggs float.
It is also known that eggs have a density between that of salt water and freshwater.
Let us find out who is deceiving whom in this mystery!

Engage

WHAT'S INTERESTING?

Task: A farmer is selling eggs at a market and he is demonstrating that his eggs are fresh by placing them in freshwater. He is selling a lot of eggs, so the farmer in the neighbouring market stall is getting envious. He challenges the farmer by claiming his eggs are rotten. As evidence, he takes one egg and put it in a solution which he claims is pure water. The egg floats and the customers are worried they have been deceived.

Who is deceiving whom?

Explore

WHAT'S HAPPENING?

Task: Both farmers cannot be right: one of them is cheating in some way. Can you describe an experiment in which you investigate this matter? In order to get started, think about the following: Is it easier to swim in the ocean or a lake?

What makes things float? The object or the medium it floats/sinks in?

Useful equipment might be a weight, measuring cylinder, hot plate, and salt.

Explain

WHAT'S CAUSING IT?

Task: Describe your experiment and how it can cast light on the quarrel between the farmers. Who is tricking whom?

Discuss possible sources of error.

Extend

WHAT'S SIMILAR?

Task: Boats made of wood and steel float equally well. However, from the previous investigation, it should be clear that dense objects sink. How is it possible that a boat made of steel does not sink?

Discuss or experiment with objects (for example, model clay) in order to find out how this can be the case.

Take a look at this animation:
http://www.bigs.de/BLH/en/images/stories/physik/anim/wssab01.swf

Explain what is happening in this simulation (very difficult: requires a knowledge of buoyancy).

Does the salt evaporate as well as the water?

Use the Hypothesiser Lifeline to design a new experiment to test this.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Answer the following questions:

Make sure you know the difference between the terms 'heavy' and 'dense'.

After conducting this investigation, why do you think it is easier to float in the sea than in a lake?

When you inhale while swimming, it is difficult to dive. Why?

How would you improve your experiment?

The Book of Science Mysteries

The chameleon bubbles

What's the mystery?

Chameleon bubbles are alginate bubbles that emerge when a sodium alginate solution is dropped into a calcium chloride solution – just like how bubbles in bubble tea are made.

The bubbles can change their colour with respect to the substance with which they are filled. In this case, the bubbles are filled by an acid-base indicator solution; so, adding acids or bases in the outer surrounding leads to colour changes inside the bubbles by diffusion and pH change – just like how a chameleon can change its colour. Since acids and bases are colourless liquids, adding them to the solution around the bubbles leads to mysterious colour changes.

DOMAIN(S)

Chemistry, acid-base chemistry.

SUBDOMAIN KEYWORDS

Sodium alginates, acids, bases, indicators, semi-permeable membrane.

AGE GROUP

14 to **15** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
15 min.

Approximate time in classroom:
90 min.

SAFETY/SUPERVISION

Students should wear safety goggles and lab coats.
Acids and bases are corrosive.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Sodium alginate
- Calcium chloride
- Diluted hydrochloric acid
- Diluted sodium hydroxide solution
- Salad herbs
- Vinegar
- Vegetable oil
- Red cabbage indicator
- Other indicators.

LEARNING OBJECTIVES

Students can learn about acids, bases, indicators, neutralisation, and diffusion through semi-permeable membranes.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Students generally know about bubble tea. However, bubbles that change their colours are unfamiliar to students. The teacher can engage students with a fictitious story about a child's birthday. Someone prepared bubbles for lemonade and put red cabbage juice or radish extract inside them. Once these were put into the lemonade, they started to change their colour. This helps the children to become curious about why this happened.

Explore

COLLECT DATA FROM EXPERIMENTS

1. The colour within the alginate bubbles changes with the addition of acids and bases; this begins a process of neutralisation. The effect of the semi-permeable membrane of the alginate bubbles can be observed.
2. Testing the behaviour of an alginate solution indicates the special character of this substance. Proper work is necessary to prevent the formation of lumps.
3. Alginates do not form homogeneous solutions in some surroundings; instead, some kind of glue or gel is formed. When testing the (vinegar-oil) salad dressing herbs get into some kind of suspension. In an aqueous solution, the water would separate from the oil again.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

With the addition of an acid, the oxonium ions diffuse through the alginate membrane inside the bubbles. With the addition of a base, the hydronium ions diffuse through the membrane. Any acid-base indicator will indicate the corresponding pH change and processes of neutralisation. Alginates are polysaccharides. Positively charged calcium ions insert themselves between negatively charged alginate molecules. Sugar molecules create a network, thus forming a semi-permeable membrane.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

The students can search for information about the hype surrounding the bubble tea business in 2010. They can then comment on the topic and discuss the very critical attitude of the media towards bubble teas. Students can also find more information on the technical use of semi-permeable membranes and learn about molecular gastronomy.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Reference can be made to the idea of environmentally friendly packaging, since plastic water bottles could be replaced with ones made from alginates. The practicality of this idea can be assessed. Based on the experiment, the students can estimate the carrying capacity of the semi-permeable membrane and use the findings to devise an opinion.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The engage phase can be structured by telling a story about a child's birthday, where the parents wanted to make the lemonade more exciting by adding homemade bubbles filled with some vegetable-based coloured liquids. The story can be supported with an experimental presentation. The bubbles are put into lemonade. After a short time, the colour changes. This can be seen more clearly if the bubbles are removed from the lemonade and placed in a petri dish in front of the students.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The mystery is presented as a guided enquiry (level 2). The students complete the tasks in order to investigate alginates and colour changes. A variety of materials is made available to the students so that they can solve the mystery autonomously and find an explanation on their own.

Solving the mystery: by producing and examining the alginate solution, the students realise that this is not an aqueous solution; rather, it is a gel.

By bringing the bubbles into contact with various household acids and bases, a colour change can regularly be observed. The colour appears slowly in the shell; before long, the bubbles are coloured completely. It can be observed that the alginate shell works as a semi-permeable membrane. This can be passed by oxonium and hydroxide ions, but not by the bigger indicator molecules. Using the various acids and bases, it becomes clear that there is an acid and base reaction taking place: the indicator demonstrates this.

Resources

Brandl, H. (1998). Trickkiste Chemie. Bayerischer Schulbuch Verlag, München.

The chameleon bubbles

STUDENT WORKSHEET

My friend Sara works in a school kitchen. She is preparing treats for her daughter's birthday. At the moment, Sara is preparing bubbles for bubble lemonade: a drink similar to bubble tea. The guests can put the bubbles in their drinks if they like. Of course, the children also start playing around with the bubbles. However, one of them suddenly cries out. There's something really strange happening: check out what the child experienced.

Engage

WHAT'S INTERESTING?

Task: Drop sodium alginate solution with a plastic pipette into the calcium chloride solution.

Examine the behaviour of the bubbles with the following materials and chemicals: glass beaker (fill with water), spoon, petri dish, knife, diluted hydrochloric acid, and diluted sodium hydroxide solution.

Describe your observations and suggest questions.

Explore

WHAT'S HAPPENING?

Task 1: Suggest ideas to solve the mystery of the chameleon bubbles.

Task 2: With the materials (scales, spatula, thermometer (70°C), sieve, glass rod, hot plate with magnetic stirrer, and beakers (250 ml and 50 ml)), produce sodium alginate and sodium alginate solution. Describe the properties and behaviour of the sodium alginate solution.

Task 3: Examine the behaviour of the sodium alginate solution when it comes into contact with salad dressing made from oil, vinegar, and herbs. Use sodium alginate solution, salad herbs, vegetable oil, vinegar, water, beakers, a hot plate with magnetic stirrer, test tubes, and a test tube rack.

Task 4: Examine the behaviour of the sodium alginate solution in a calcium chloride solution with different pH values. Use glass beakers, glass rods, tweezers, a pipette, a microscope, diluted hydrochloric acid, diluted sodium hydroxide solution, a red cabbage indicator, and other indicators.

Explain

WHAT'S CAUSING IT?

Task 1: Write down your observations about the properties of the sodium alginate solution.

Task 2: Explain how the colour change in the balls occurs.

Task 3: Search the Internet for the phenomenon of spherification and explain it using the following terms: calcium ions, alginate molecules, membrane, positively charged, negatively charged, networking, semi-permeable.

Extend

WHAT'S SIMILAR?

Task: Bubble tea was a very popular trend that spilled over from China to Europe a few years ago. However, it vanished just as quickly as it emerged. Many of the newly opened stores had to close.

Search the Internet to find out about the history of bubble tea. Rate how the media handled this product and form an opinion.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: The environment plays a big role in our society. So the idea quickly emerged that alginate membranes could be used to transport water. This means that plastic bottles might be replaced in the future by edible packaging.

Give your opinion on this idea. Think about the criteria that such a package needs to meet and whether this can be guaranteed. Include your results from the experiments for evaluation.

The Book of Science Mysteries

The clock reaction

What's the mystery?

Two translucent liquids are mixed. At first, nothing happens: the resulting solution is still translucent. Suddenly, with no warning, the solution turns blue-black all at once.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Redox reactions, rate of reaction (kinetics).

AGE GROUP

15 to **17** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation: up to **one hour** for preparation of the solutions and trials to ensure that the reaction takes place as planned.

Approximate time in classroom: up to **six periods of 45 mins** each (one period to engage and explore, one to explain, and three to plan, perform, and present the creative activity that incorporates the colour change).

SAFETY/SUPERVISION

Iodine (I_2) is produced in the reactions. The reaction vessels should be tapped. At the end of the reaction, the iodine produced should be neutralised with $Na_2S_2O_3$ solution.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Potassium iodide, KI 0.1M (solution A).
- Hydrogen peroxide, 3 % $H_2O_{2\,(aq)}$ in an acidic environment + starch (solution B).
- Sodium thiosulphate, $Na_2S_2O_3 \bullet 5H_2O$ ~0.05M (solution C).
- Neutralising solution: sodium thiosulphate, $Na_2S_2O_3 \bullet 5H_2O$ ~0.05M (the solution is the same as solution C. It is written separately to remind that an additional amount for neutralisation is necessary).
- 3 × 10 ml graduated cylinders
- 3 large test tubes
- Suitable test tube rack
- 3 rubber stoppers for the test tubes
- 3 plastic pipettes

LEARNING OBJECTIVES

Introduction of interesting Redox reactions.

Introduction of reaction rates, the effects of fast and slow reactions, and their uses.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The student watch the following silent movie on the TEMI Youtube Channel: www.goo.gl/tUDaq5
Playlist> Engage pantomime (Video 1)

While watching, they write down observations and questions.

If the movie cannot be shown, the teacher can conduct the experiment live. Suitable amounts of solutions A and C are mixed in a jug. Solution B is poured into a wine glass. The solutions in the jug and in the wine glass are mixed and poured back and forth until the solution has changed colour.

During the process, the teacher tells a short story; for example, "I ran out of blackcurrant juice, so I bought water; with magic and some chemistry, I have turned it into juice."

Explore

COLLECT DATA FROM EXPERIMENTS

Students are asked to perform experiments which will guide them step by step (1–3) to understanding the clock reactions.

① Students mix solutions A and B. This immediately generates a black colour.

② Students mix solutions A and B in the presence of solution C; the appearance of colour is delayed. Each student group receives a different volume of solution C, causing different delays in the appearance of the colour.

③ A representative from each group is asked to perform experiment (2) together with all the other representatives before the class. The black colour appears at different times, thus forming a visual 'xylophone' (see on the TEMI Youtube Channel: www.goo.gl/tUDaq5
4 Explore 3 Explain (Video 3))

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Students are given information regarding the reactions that occur. They are also told that starch is an indicator for the presence of iodine and that the presence of both in a solution causes it to change to a black colour. Students are then asked to explain the phenomenon.

The full explanation is as follows.

Two competing reactions are taking place in the reaction vessel:

① $H_2O_{2\,(aq)} + 2H_3O^+_{(aq)} + 2I^-_{(aq)} \rightarrow I_{2(aq)} + 4H_2O_{(l)}$

② $2S_2O_3^{2-}{}_{(aq)} + I_{2(aq)} \rightarrow S_4O_6^{2-}{}_{(aq)} + 2I^-_{(aq)}$

Reaction 1: oxidised iodide, I-(aq), into iodine, I2. The latter appears black in the presence of starch.

Reaction 2: the reduction of the iodine back into colourless iodide.

Since reaction **2** is faster than reaction **1**, the solution remains colourless: any iodine formed is quickly transformed into iodide.

These two reactions occur simultaneously until the thiosulphate ions ($S_2O_3^{2-}$), the limiting agents, run out. When this happens, only reaction 1 takes place: all iodide turns to iodine and the solution becomes black.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

The teacher collects data from the different groups regarding the time at which the black colour appeared and the volume of the inhibiting solution. The class analyses the data using a table on the board and draws a graph of the inhibitory solution's volume against the time of the black colour's appearance.

The trend line and the mathematical equation of the slope on the graph are used to explain the concept of the calibration graph and its use.

Students are asked to design an experiment in which the appearance of the black colour is synchronised with a sound change in a song or with any other creative element.

Each group presents the plan of the experiment before the class.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students prepare a lab report which assesses skills such as making observations, asking questions, designing an experiment, writing explanations, and hypothesising. Students have to explain why the experiment is called the 'clock reaction'.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The engage stage can be completed by showing **video 1** or by performing the clock reaction on a large scale. If the teacher feels comfortable, we suggest and encourage telling a story relevant to the students.

The explore stage **(1–2)** is self-explanatory (**video 2)**. While performing in front of the class **(3)**, the teacher has to direct the performance in the following way:

1. All the students stand in a line and wait to mix solution B at the same time. The teacher may order them by the volume of solution C or in a random manner.
2. The 'stage' should help students focus on the reaction **(video 3)**; this can be done by:
   a. Putting white paper as a background below and behind the reaction containers.
   b. The reaction takes time, so think what to say while the reaction occurs: "what do you expect to see?", "which will appear next?", etc.

The extend stage should be an event in class. Each group presents their chosen song and there should be 'tension' over whether the colour change is synchronised with the music.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The lesson begins with a demonstration of the mysterious phenomenon (the engage stage). During the demonstration, students also see the teacher mix the reaction.

In the explore stage, they imitate the teacher's actions and follow strict instructions. The students need to use and understand the idea of a calibration curve to perform the extend stage. In the extend stage, they are encouraged to 'own' the reaction and control it so that it 'performs' in accordance with a song they like.

Students thus gain control of planning and engineering the reaction.

During the activity, students learn the following enquiry skills: engagement in scientific questions, giving priority to evidence, formulating explanations from evidence, connecting explanations to knowledge, graphic representations, and calibration graphs and their meaning.

Resources

The following videos suggest ways in which the mystery can be presented. TEMI Youtube Channel: www.goo.gl/tUDaq5

>Playlist

For the engage stage:

Video 1: Video 1 Engage pantomime

For the explore stage:

Video 2: Video 2 2 Explore 1

Video 3: Video 3 4 Explore 3 Explain Engage

The clock reaction

STUDENT WORKSHEET

Two translucent liquids are mixed. At first, nothing happens: the resulting solution is still translucent. Suddenly, with no warning, the solution turns blue-black all at once.

You will see a demonstration of a mysterious chemical reaction. How does the reaction know when to turn black? Is there some magical ingredient that can't be seen? Does the teacher add some mysterious chemical when we aren't looking, or is the mysterious chemical already in the reaction vessel?

We will try to decipher a reaction that 'has a mind of its own'.

Engage

WHAT'S INTERESTING?

Task: Watch the following silent movie on the TEMI Youtube Channel:
www.goo.gl/tUDaq5
Playlist> Engage pantomime

What happens in the video? Why do you think this happens?

While watching, write what you see and pose some questions relating to what is happening. You may watch the video more than once.

Explore

WHAT'S HAPPENING?

Task: You will get three solutions:
Solution A – Potassium iodide, KI 0.1M

Solution B – Hydrogen peroxide, 3 % $H_2O_{2\,(aq)}$ in an acidic environment + starch

Solution C – Sodium thiosulphate, $Na_2S_2O_3 \bullet 5H_2O$ ~0.05M

You will also get the following materials:

- 3 × 10 ml graduated cylinders
- 3 large test tubes
- Suitable test tube rack
- 3 rubber stoppers for the test tubes
- 3 plastic pipettes
- Stopwatch
- Gloves, which must be worn at all times

Mark the three cylinders with the letters **'A'**, **'B'**, and **'C'**. Make sure that you always use one cylinder for each solution.

a. Measure 5 ml of solution A using the graduated cylinder marked 'A' and pour it into a large test tube.

b. Measure 10 ml of solution B using the graduated cylinder marked 'B'.

c. Pour solution B into the test tube containing A. Close the test tube with a stopper, mix lightly, and write your observations.

d. Measure 5 ml of solution A using the graduated cylinder marked 'A' and pour it into a clean large test tube.

e. Measure 3 ml of solution C using the graduated cylinder marked 'C' and add them to the test tube containing A.

f. Measure 10 ml of solution B using the graduated cylinder marked 'B'.

g. Pour solution B into the test tube containing solutions A and C. Start the stopwatch, close the test tube with a stopper, mix lightly, and write your observations.

h. Repeat instructions d–g in the class presentations according to the teacher's instructions.

Explain
WHAT'S CAUSING IT?

Task 1: Try to explain your observations based on the following reactions:

① $H_2O_{2\,(aq)} + 2H_3O^+_{(aq)} + 2I^-_{(aq)} \rightarrow I_{2(aq)} + 4H_2O_{(l)}$

② $2S_2O_22^-_{(aq)} + I2_{(aq)} \rightarrow S_4O_6^{2-}{}_{(aq)} + 2I^-_{(aq)}$

Task 2: The teacher will gather the findings of all groups in class. How do you suggest we present the data?

Extend
WHAT'S SIMILAR?

Task: In your groups, plan a creative activity that is based on and incorporates the colour change. For example, so that the solution changes its colour at a highlight in a song.

Plan an experiment, including the following stages:

- » Detail all the steps of the experiment.
- » List the equipment and materials needed on the equipment request form.
- » Consult the teacher and make changes if necessary.
- » Submit the list of equipment and materials to the laboratory technician.

Evaluate
WHAT'S MY UNDERSTANDING?

Task 1: Present the creative activity that incorporates the colour change.

Task 2: Prepare a formal lab report that includes an explanation of the phenomenon and the details of your methods and procedures.

The Mentos-Cola fountain

What's the mystery?

The Internet provides a large number of videos about the Mentos-Cola fountain. There are also several media available that present the phenomenon as a challenging show event. The challenge is to produce as high a fountain as possible. To do this, students need to enquire into the reasons and functioning behind the Mentos-Cola fountain trick.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Solubility, gases, carbon dioxide, fizzy drinks.

AGE GROUP

13 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation: do not mention it.

Approximate time in classroom: **90 min. lesson.**

SAFETY/SUPERVISION

No hazards.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Beakers
- Soft drinks (apple juice, cola, diet cola (cola light), orange lemonade, sparkling water)
- Sweets (Mentos, fruit gum drops, sugar-free Mentos, sugar cubes)
- Spoons.

LEARNING OBJECTIVES

Students will learn about the solubility of gases.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher can present any video of the Mentos-Cola fountain from the Internet. The students might need to create a fountain by themselves. The students might do this experiment themselves outside of the classroom. The students will see that, normally, the fountain is not as high as in most Internet videos. This will provoke questions and engage the students. Potential questions might include: how does the fountain work? Which factors influence the size of the fountain? Does the experiment also work with other sweets or drinks?

Explore

COLLECT DATA FROM EXPERIMENTS

The students can perform different experiments to find out how the fountain works. They should explore the experiment by varying the sweets, drinks, and other conditions. By comparing the different sweets and drinks, the students can exclude irrelevant variables. The causes for the fountain are the solved carbon dioxide as well as the rough surface of the Mentos sweets.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

It is the surface of the Mentos that causes the fountain. The rough surface structure leads to the very fast elusion of the dissolved carbon dioxide from the cola. Rough surfaces allow dissolved gases to elude much faster than they normally do. This process is so fast that the eluding gas carries large amounts of cola out of the bottle.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

After the students have worked intensively with the Mentos-Cola fountain, they will wonder what actually happens when you place cola and Mentos into the mouth at the same time. Here, various entries on Internet forums can be found which discuss such issues. The different contributions can be analysed, commented upon, and evaluated.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

After the mystery has been solved, the students will want to carry out the experiment. Here, you can test the contents explored in the task to maximise the fountain. Thus, the task is a little more exciting, since you can make this a competition. A competition that focuses on the height of the fountains can be held outdoors.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

A number of videos about the Mentos-Cola fountain can be found on the Internet. Thus, the most amazing videos of the phenomenon can be presented and the potential sizes of the fountains can be evaluated. A fountain can also be demonstrated by the teacher outdoors. Generally, the results will not be nearly as high as in the Internet videos. This observation regularly results in many questions; e.g., how the size of the fountain can be manipulated or how it works at all.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The mystery is presented as a guided enquiry (level 2). Generally, many students know about the phenomenon already. However, most students do not know why the fountain occurs. Learners should therefore make first guesses and formulate questions to find ideas to explore. Students can develop a lot of ideas about the phenomenon.

Solving the mystery: the students will consider that the fact that dissolved carbon dioxide plays a role. The different sweets make clear that a certain surface is required. Students will realise that the surfaces of the Mentos are responsible for the fountain.

Resources

There are a number of YouTube videos showing the extent of Mentos-Cola fountains. You can watch them on the TEMI Youtube Channel:
www.goo.gl/tUDaq5

- playlist > Diet Coke + Mentos
- playlist > Mentos küsst Cola Weltrekord mit EepyBird

The Mentos-Cola fountain

STUDENT WORKSHEET

On the Internet, there are many different videos presenting the Mentos-Cola fountain. The fountains generally reach heights that are difficult to achieve. The fountains are so high that world records are achieved; equally, artistic shows have been performed with cola-Mentos fountains. Solve the mystery and develop ideas about how to break the world record.

Engage

WHAT'S INTERESTING?

Task: Take a Mentos, a fruit sweet, and a fruit gum. Place each in a small beaker with cola. Compare the effects and describe the differences. Write down the questions that arise from your observations.

Explore

WHAT'S HAPPENING?

Task 1: Suggest ideas to solve the mystery of the Mentos-Cola fountain.

Task 2: Explore the behaviour of Mentos in small beakers with various drinks. You may use the following drinks: plain water, apple juice, cola, cola light, orange lemonade, sparkling water, tea, etc.

Task 3: Explore the behaviour of different sweets in cola. You may use the following sweets: full-sugar sweets, chewing gum, Mentos, sugar-free sweets, sour fruit sweets, chocolate, etc.

Explain

WHAT'S CAUSING IT?

Task 1: Explain which properties of Mentos and cola are responsible for the emergence of the fountain.

Task 2: Explain what is happening during the formation of the Mentos-Cola fountain.

Extend

WHAT'S SIMILAR?

Task: "Does one explode if one eats Mentos, drinks cola, and is shaking the body heavily?"

On an Internet forum, a user asked the question above and wanted to get an answer. It is probable that he or she does not really believe the body will explode because of the reaction. However, it seems as if he or she is uncertain; after all, a cola bottle can be exploded with a Mentos.

Discuss the question with regards to the physical and physiological aspects of the issue and suggest an answer.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: As can be seen in many videos on the Internet, it is the goal of some people to generate a Mentos-Cola fountain that is as high as possible.

Suggest potential factors that will influence the size of the Mentos-Cola fountain. Describe further experiments to potentially check whether your suggestions would be helpful in producing the highest fountain ever.

The Book of Science Mysteries

The murder of the jeweller Beketov

What's the mystery?

The mystery revolves round a detective story which the students gradually solve. A jeweller has been murdered: the suspects are his metal suppliers but the motive and the culprit are initially unknown.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Electrochemical series of metals, properties and reactions of metals, periodic system of the elements.

AGE GROUP

14 to **18** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation: **30 min.**

Approximate time in classroom: **two 45 min. lessons.**

SAFETY/SUPERVISION

The experiments use a five per cent solution of HCl: this is an irritant. Caution and protective gloves are needed.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Text of a detective story for each group of students
- Common chemical equipment (test tubes, pipettes, petri dishes and pincers)
- Solutions ($AgNO_3$, $Al_2(SO_4)_3$, $ZnSO_4$, HCl: everything is diluted at, for example, five per cent concentration)
- Solid metals (Zn, Al, and some silvery metal with a look and shape similar to silver, possibly Sn or Fe).

LEARNING OBJECTIVES

Students learn about the redox properties of metals, which are the base of the electrochemical series of metals. This series of metals was first assembled by the Russian chemist N. N. Beketov in the 19th century, which is why it is sometimes called the Beketov's series of metals, and it is also why we used his name in our story. V. V. Markovnikov was also an important Russian chemist of the 19th century.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Students look for papers with parts of a detective story and arrange them to make sense. It is a murder mystery: why were the jeweller, Beketov, and the investigator, Markovnikov, murdered?

Explore

COLLECT DATA FROM EXPERIMENTS

Students have samples of the various metals with which the jeweller worked. They find out the metals' properties by looking at the chemical reactions between them and their salts. They present their results in the worksheet.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Metals are divided into two groups according to their reactivity. More reactive metal reacts with the salt of a less reactive metal and becomes a part of the salt, while the less reactive metal comes out of the salt pure. Through the experiments, the students should find that Beketov found out that his supplier gave him tin (Sn) instead of silver and the supplier killed him. The investigator was coming close to finding out about this deception so he too was killed.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

This topic is a part of the curriculum (electrochemical series of metals/Beketov's metal series). It is connected with the common usage of metals (iron corrodes fast while gold doesn't corrode for thousands of years). This redox reaction is also the principle behind some kinds of batteries.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students should fill in the table correctly according to the results of their experiments. These will show them a part of the series of metals. The teacher fills in the rest of the series and continues by explaining and discussing the applications of this knowledge.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Students can pose their questions on the basis of the detective story (see below). The story is cut into pieces and scattered around the lab, classroom, corridor etc. Students need to find the pieces of the story and put them together. They then need to conduct experiments and assess the evidence. On the basis of this, they should explain the sequence of events in the murder. The teacher is there to supervise their hypotheses and maybe nudge them in the right direction if they seem lost.

1. At 3PM, the police are called to the murder of the jeweller Beketov.
2. The policemen discover the jeweller, Beketov, in his shop on the main street with his skull bashed in.
3. The eyewitnesses claim that Beketov was provably alive and well at 1PM.
4. After questioning Mr. Beketov's helper, it was found that one of the suppliers arrived to the shop around 2PM.
5. It is not known which supplier arrived on that fateful afternoon: all three suppliers to the jeweller have an alibi for that time.
6. The police decide to give the newspapers the information that one of the suppliers is the murderer, believing this will scare him and make him confess.
7. In the morning after the newspaper article about the suspected suppliers comes out, the dead body of the policeman, Markovnikov, is found in the jeweller's workshop surrounded by chemicals and equipment.
8. It was found that the policeman, Markovnikov, was killed by a blow to the head during a chemical experiment which, according to his colleagues, was supposed to reveal the murderer.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: tell the students that a jeweller has been murdered and their help is needed to solve the mystery.

Demonstrated enquiry (level 0): the teacher reads out the murder story to the students and suggests a way to continue the experiments. The teacher says that some metals react differently than others and maybe the supposed silver is some other metal. Students record their thinking onto their hypothesiser lifeline worksheet.

Structured enquiry (level 1): students then use their Hypothesiser Lifeline sheet to record their own alternative ideas about the murder and to record their tests and conclusions regarding these other explanations.

Solving the mystery: students are led towards the explanation by using ideas about the electrochemical series of metals derived from their experiments. They will thus find out that the supposed silver was in fact tin. The jeweller found out and that was why he was murdered. The investigator was very close to finding out the culprit so he was killed too.

Resources

You can find examples of reactions between reactive metals and salts of less reactive metals in the videos on the TEMI Youtube Channel: www.goo.gl/tUDaq5

Reaction between copper and silver nitrate:
playlist> Silver Tree
playlist> Silver Christmas Tree

Reaction betwenn iron and copper sulphate:
playlist> Chemistry Revision - Iron & Copper Sulphate solution

The murder of the jeweller Beketov

STUDENT WORKSHEET

Initially, familiarise yourself with the story about the murders of the jeweler, Beketov, and the police commissioner, Markovnikov. Then, work out the experiments which will help catch the murderer by discovering which metal supplier killed Beketov and Markovnikov using the chemical experiment you devised.

Engage

WHAT'S INTERESTING?

Task: Work in pairs. Go outside the lab in turns with your partner and find strips of paper with pieces of the story. Put the pieces together so that the story makes sense.

Explore

WHAT'S HAPPENING?

Task 1: Suggest ideas to help solve the murder.

Task 2: Explore the behaviour of various metals (zinc, aluminium, and silver) in small test tubes with various solutions (salts of metals in water). You may use the following solutions: $AgNO_3$, $Al_2(SO_4)_3$, $ZnSO_4$, HCl. What experiments would be useful in providing evidence to assist you in solving the murder? Write your results into the table in the worksheet.

Explain

WHAT'S CAUSING IT?

Task 1: Sort the metals into a series according to the table.

Task 2: Explain why the metals are in this order. Note the various reactions of the metals with HCl: would silver react with HCl?

Task 3: Solve the murder!

Extend

WHAT'S SIMILAR?

Task: Try the same experiments with other metals and solutions of these metals' salts (for example, Mg and $MgSO_4$, Fe and $FeSO_4$, or Cu and $CuSO_4$). What do you find?

Write your results into the table on the next page and add these metals into the series.

Markovnikov's advice:

» Metal reacts – **2 points**

» Metal is in the solution of the same element's salts – **1 point**

» It didn't even perform the reactions – **redundant**

» Metal doesn't react at all – **0 points**

» After that, add up the points and form the metal series in ascending order.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Find some practical examples for using this series of metals in real life; for instance, what metal would you use for making long-lasting jewellery?

	$AgNO_3$ Name:	$Al_2(SO_4)_3$ Name:	$ZnSO_4$ Name:	HCl Name:
Ag				
Al				
Zn				
Total Points:	Silver	Aluminium	Zinc	Hydrogen

The mystery of Gibraltar

What's the mystery?

Sailors who were passing through the strait of Gibraltar observed a strange fact. They found that water was pouring into the Mediterranean, a land-locked sea which also has many rivers flowing into it; however, the sea level is not going up all the time. How could this be?

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Solutions and their properties.

AGE GROUP

12 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
40 min.

Approximate time in classroom:
two 45 min. lessons.

SAFETY/SUPERVISION

No restrictions needed.

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PREPARATION AND LIST OF MATERIALS

» A story about the observations of the sailors
» Salt
» Food colouring.

LEARNING OBJECTIVES

Students learn about the solutions of a particular substance which can have various concentrations and thus various densities. These properties have an impact on the behaviour of the solutions.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

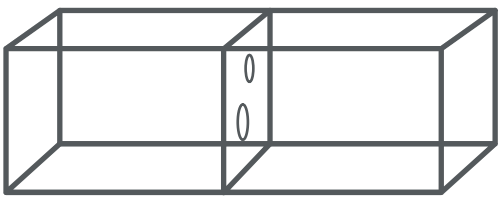
Tell the story about how in ancient times sailors found out that there's a strong current in Gibraltar from the Atlantic to the Mediterranean. They also knew that the Mediterranean is surrounded by land. How can the water flow in and not out?

What factors make water flow (difference in height, temperature, pressure, salinity, etc.)? Do they apply to this case?

Explore

COLLECT DATA FROM EXPERIMENTS

The students can try to explain this mystery with their prior knowledge about salt water and pure water and come to the explanation of difference in salinity due to evaporation in the Mediterranean. The students can prove this hypothesis by demonstrating an experiment with two bodies of differently coloured water: one is pure water (the Atlantic) and the other is a salt solution (the Mediterranean). First, the students can try out pouring these liquids over each other with drinking straws. Second, they can make their own model of the strait of Gibraltar (see below) with a plastic box. Put duct tape over the holes, pour the two solutions into the two halves, and remove the tape: you will see two different layers and currents.



Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Due to the different densities of the water, the water flows through the holes and forms two layers. There is a current flowing back from the Mediterranean to the Atlantic but it's near the bottom of the sea; thus, the ancient sailors had no way of knowing about it.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

This is the way ocean currents work. There are also some other experiments with salt water (the floating egg, the testing of ripeness of fruits, etc.) that can be used to reinforce ideas about the density of different salinities of water.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students are evaluated in a group discussion. The teacher asks questions to see if they have understood the concept correctly and what they learnt from the lesson.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The teacher can first tells the class a story about sailors trying to figure out how does the Strait of Gibraltar work – how come the water seemingly only flows in one direction? Where does it go?

The story should increase curiosity about the subject in students. It is also possible to show a video of ocean currents etc.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: tell the class a story about sailors sailing through the strait of Gibraltar.

Demonstrated enquiry (level 0): the teacher shows the class the coloured water model of the strait with the horizontal layers. He or she asks about the explanation and the difference between these two layers apart from the colour. The teacher thinks aloud about the salinity of the sea and that maybe the two layers have different salinity levels. The students record their thinking onto their hypothesiser lifeline worksheet.

Structured enquiry (level 1): students use their hypothesiser lifeline sheet to record their own alternative ideas about why the Mediterranean does not rise infinitely and to where does the water disappears. They also record their tests and conclusions regarding these other explanations.

Solving the mystery: students are led towards the explanation by using ideas about salinity and different densities of differently concentrated solutions of salt and other substances.

Resources

You can see the first experiment here:
TEMI Youtube Channel
www.goo.gl/tUDaq5
playlist > Water density

For an overview of the ocean currents in the Mediterranean:
TEMI Youtube Channel
www.goo.gl/tUDaq5
playlist > Ocean current flow

The mystery of Gibraltar

STUDENT WORKSHEET

The Gibraltar strait is where the Atlantic Ocean meets the Mediterranean Sea.
But there is something strange going on...

Engage

WHAT'S INTERESTING?

Task: The Mediterranean always seems to be thirsty: there is a strong current flowing into it from the Atlantic through the Gibraltar strait. However, the water has no way out of this sea, since it is surrounded by three continents... or does it?

Explore

WHAT'S HAPPENING?

Task 1: Can water only flow into the Mediterranean and not out? Or is there another way out we don't see?

Task 2: How salty is the water in the Mediterranean compared to the Atlantic? Is it important?

Explain

WHAT'S CAUSING IT?

Task 1: The density of water is affected by its salinity. What happens when two different types of water meet?

Task 2: Explain why we'd expect a second current in the Gibraltar strait. Why did the sailors only notice the one flowing into Mediterranean?

Extend

WHAT'S SIMILAR?

Task: The world's oceans have a complicated network of currents. Are they all based on salinity or is there another factor that affects the density of water?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Why exactly is the Mediterranean saltier than the Atlantic in the first place? What factors account for this?

The mystery of the disappearing laboratory report

What's the mystery?

This mystery deals with a laboratory report in which the written results suddenly vanished. The students need to find out how the writing vanished, how to recover the vanished data, and what the secret of the pen is.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Energy (exothermic and endothermic reactions), chemical equilibrium, thermodynamics.

AGE GROUP

16 to **17** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
One hour to prepare the lab reports (writing them and warming them up to make the ink disappear).

Approximate time in classroom:
Up to **six periods of 45 min** each: one period to engage and explore, one to explain, three for open enquiry, and one to present the enquiry in class.

SAFETY/SUPERVISION

None. If there is use of liquid nitrogen, the safety regulations related to its use are necessary.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» A pilot friXion ball erasable ink pen for each group of three to four students.
» A lab report with missing/erased data.
» Different equipment to heat and cool the paper (such as a kettle, hair dryer, or liquid nitrogen).

LEARNING OBJECTIVES

Exposing students to reversible chemical reactions. Experimenting with the conditions that influence such reactions.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher tells a story about how she/he left students' lab reports in a hot place (such as in a car in summer or in front of a fire place); the next day, when the teacher looked at the reports, most of the data had disappeared. Alternatively, the teacher can hand out greeting cards (for the new school year, for a holiday, etc.) in which half of the text is missing.

Explore

COLLECT DATA FROM EXPERIMENTS

Students can try to make the ink reappear. They can suggest and try their own ways of making the ink reappear. Students often suggest actions such as heating or cooling the paper to different temperatures, exposing the paper to different levels of pH, or exposing the paper to light at different intensities.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

The ink is made of a thermochromic pigment, which is sensitive to temperature changes. As the ink is exposed to high temperatures, it changes from coloured to colourless. This property is exploited to make erasable ink: when ink is applied on paper rubbed with a special plastic (on the cap of the pen), the heat caused by the friction makes the ink disappear.

However, this is a reversible reaction and the colour can be made to reappear upon cooling.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Students can design their own enquiry-based experiments based on their knowledge of thermodynamics, energy and Le Chatellier's principle to explore the thermochromic properties of the ink. This enquiry is open ended: the questions should come from the students.

Sample questions could be: "at what temperature does the ink disappear?", "at what temperature does the ink reappear?", "can the process be made non-reversible (e.g. by overheating the ink)", and "if the pen is heated, can it be used to write invisible scripts?"

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students are assessed via two methods. They should prepare a formal written lab report and an oral presentation of the lab report in class. The written and oral lab reports assess skills like making observations, asking questions, designing experiments, writing scientific explanations, and proposing hypotheses. The oral presentation further allows for discussion and for presenters to improve their lab reports.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The engaging story has to be relevant to the teacher and the scenario in class. It can relate to a recent lab report, an upcoming holiday, etc.

As an additional exercise, students may draw a picture that 'uses' the phenomenon of the disappearing/reappearing ink to express an idea and show it. This could be a good way to encourage students to use some showmanship in the presentation.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The activity begins with the presentation of the mystery. In the first stage (explore), students conduct a structured enquiry (level 1) in order to understand the phenomenon and solve the mystery.

In the extend stage, students conduct an open-ended enquiry (level 2). Here, with the help of the teacher, they learn to ask research questions, design an experiment, carry out the experiment, process the data, and reach conclusions based on the data.

Resources

More on the phenomenon can be found at the following website:

www.tmchallcrest.com/chromazone/Thermochromism.htm

The mystery of the disappearing laboratory report

STUDENT WORKSHEET

Yesterday we had great results at the lab! We explored different kinds of reactions, measured the temperature vs time for all of them and organized the data in beautiful tables. We thought about every detail! Titles, units, observations-everything was there!! We were so tired and proud, that we decided that we deserve a break on the beach in this hot summer day. When we came back and opened our notebook, we were shocked to see that our data was gone! The outline of the table was there, but the data was gone!

Engage

WHAT'S INTERESTING?

Task 1: Suggest relevant observations or questions that need to be considered in order to resolve the mystery of the missing data and to write 'the story of the table'.

Task 2: Suggest how to make the missing data in the lab report you received reappear.

Explore

WHAT'S HAPPENING?

Task 1: Ask for materials and equipment to try and make the ink reappear. Explore the behaviour of the ink.

Task 2: Describe what you did and what happened.

Explain

WHAT'S CAUSING IT?

Task 1: Hypothesise about how the ink works.

Task 2: Give a reasonable explanation for your hypothesis based on the concepts related to energy transfer in chemical reactions.

Task 3: Brainstorm with the class and explain how the ink works.

Extend

WHAT'S SIMILAR?

Task 1: Write down five questions that arose while exploring the issue of the missing ink.

Task 2: Choose one of the questions that you would like to investigate regarding the 'ink' and formulate this question clearly as an enquiry.

Task 3: Clearly formulate a hypothesis that relates to the question that you chose to investigate. Give reasons for your hypothesis based on correct and relevant scientific knowledge.

Task 4: Plan an experiment that will check your hypothesis.

- Detail all the steps of the experiment, including the control stage.
- List the equipment and materials needed on the equipment request form.
- Consult with the teacher and make changes if necessary.
- Submit the list of equipment and materials to the laboratory technician.

Evaluate
WHAT'S MY UNDERSTANDING?

Task 1: Prepare a lab report.

Task 2: Draw a picture that 'uses' the phenomenon of the disappearing/reappearing ink to express an idea. If you want, think of a creative way to present the change to the class.

Task 3: Present the enquiry and your drawing in class.

The Book of Science Mysteries

The sea-sand overseas

What's the mystery?

The mystery deals with sand that stays dry when water is poured onto it. Students are requested to find ways to build sand castles with this 'dry' sand.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Chemical bonding, hydrophobic and hydrophilic properties.

AGE GROUP

15 to **17** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
About an hour to prepare materials. **About an hour** to practise the story.

Approximate time in classroom:
Between **four to six periods of 45 min.** each: one period to engage and explore, one to explain, three for open enquiry, and one to present the enquiry in class.

SAFETY/SUPERVISION

No safety concerns. The materials are not toxic.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» One spoon of regular sand on a petri dish per group.

» One spoon of magic sand on a petri dish per group.

» 50 ml of water.

» 2 x 100 ml beakers.

» 2 droppers.

» During the enquiry (the extend stage), the materials depend on the research questions of the students. They may need different solvents: oil, acetone, ethanol, hexane, heptane (hydrophobic solvents which are allowed in school), soap, etc.

LEARNING OBJECTIVES

Exposing students to practical issues related to hydrophobic and hydrophilic interactions and compounds.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher tells a story about a friend who is an expert in building sand castles. The friend registers to attend a competition in a faraway place* where he has to build a castle with a strange kind of sand (the hydrophobic sand). Students are asked to help him build a sand castle with this sand.

*The teacher can tell students about a true competition that is being held; for example:
http://newzealandsandcastlecompetition.co.nz/
www.ussandsculpting.com/

Explore

COLLECT DATA FROM EXPERIMENTS

Students examine the 'dry' sand and the regular sand in order to find a solution to the problem of building a sand castle with the dry sand. They experiment with the sand, testing different solvents which will wet the sand and cause it to stick, thus allowing a person to build a castle with it.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

The phenomenon can be explained by taking a closer look at intermolecular forces and hydrogen bonding in particular. Regular sand can form hydrogen bonds with water, thus wetting the sand grains and allowing them to stick together, with the water acting as glue.

Sea-sand (the 'dry' sand) is a common aggregate that has been processed and coated with a hydrophobic material, thus preventing the grains of sand from forming hydrogen bonds with the water. The sand repels water, but it can absorb oils, other hydrophobic solvents, and pollutants.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Students can design their own enquiry based on prior knowledge related to chemical bonding and based on exploration with the sand (see 'explore' above). Here, they can check how different solvents wet the sand and allow it to stick together in order to form a castle.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students can prepare a lab report aligned with the curriculum, which assesses skills such as making observations, asking questions, designing an experiment, writing explanations, hypothesising, etc.

The results and conclusions can also be presented in a dramatic way (e.g. three still pictures).

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The full story for the engage stage can be seen in the following video on the TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > Science - The biggest drama in the class

In order to fully engage the audience, it is best that the teacher adds some of his or her own personal details to the story. For example, the teacher can mention from where they know the sandcastle-building friend. They can mention their place of birth and that they were friends from nursery school. In short, personal details added to the story can make it more vivid, credible, and engaging.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

This activity is open ended.

In the engage, stage the teacher just tells a fictional story with no demonstrations. Since this activity deals with materials from students' everyday lives, there is no need to demonstrate.

In the explore stage, students are given the freedom to conduct their own enquiries into the phenomenon. The students can pace this enquiry, with the teacher offering minimum support. At this stage, students should arrive at a solution about how to make the sand stick.

In the extend stage, students devise their own enquiry activity. Here they ask their own enquiry questions, design their own enquiry experiments, order materials, and conduct the experiments. This might be a big leap for some students; at this stage, they will need the teacher to guide their planning. The teacher's role, however, should be that of a consultant rather than an instructor.

Resources

Website for sea-sand:
http://sealsand.com/index-1.html

http://stwww.weizmann.ac.il/g-chem/temi/sand3.html

The sea-sand overseas

STUDENT WORKSHEET

Our good friend James is a champion sandcastle builder. He has won every competition in Europe. However, one day he went to a competition in Australia and all he got was this magic sand. At first he was convinced he would lose. But guess what! He built a sand castle after all! Now it's your turn: can you build a castle?

Engage

WHAT'S INTERESTING?

Task: James provided us with two types of sand: regular and special sand.

Add some drops of water to each type of sand to see what James saw when trying to build the sand castle in Australia.

Explore

WHAT'S HAPPENING?

Task 1: Try building a sandcastle from the special sand. Do you need any extra tools or materials?

Task 2: Explore the behaviour of the sand with the tools and materials you requested.

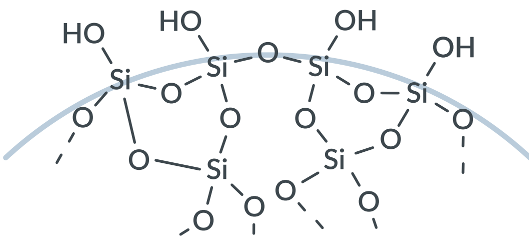
Explain

WHAT'S CAUSING IT?

Task 1: Explain the properties of the 'special' sand that prevent water from wetting it?

Task 2: What do you think the chemistry underlying the 'special' sand is?

Task 3: Look at the model on the below representing the surface of regular sand at the molecular level. How can you explain the fact that water wets this sand? In what way must the special sand be different from the regular sand on the below?



SAND SURFACE: MOLECULAR LEVEL

Extend

WHAT'S SIMILAR?

Task 1: Write five questions that arose while exploring the 'special' sand,

Task 2: Choose one of the questions that you would like to investigate regarding the 'special sand castle' and formulate this question clearly as an enquiry question.

Task 3: Clearly formulate a hypothesis that relates to the question that you chose to investigate. Give reasons for your hypothesis based on correct and relevant scientific knowledge.

Evaluate

WHAT'S MY UNDERSTANDING?

Tasks Plan an experiment that will check your hypothesis.

- Detail all the steps of the experiment, including the control stage.
- List the equipment and materials needed on the equipment request form.
- Consult with the teacher and make changes if necessary.
- Submit the list of equipment and materials to the laboratory technician.

In the next lesson, you will perform the lab experiment you devised.

The Book of Science Mysteries

The (un)reliable indicator

What's the mystery?

Students are testing different substances for the pH-value. Some students are testing crystal deodorants using a red cabbage indicator and a universal indicator. The universal indicator suggests that the deodorant reacts as an acid, whereas the red cabbage suggests that the deodorant reacts as a base. What is happening here?

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Acids, bases, indicators, complex formation, pigments, dyeing.

AGE GROUP

On a submicroscopic level: **16** to **18** years old.
On a phenomenological level: **12** years and older.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
30 min.
Approximate time in classroom:
Two to **three** individual **50 min.** lessons.

SAFETY/SUPERVISION

There are no particular safety restrictions for the suggested materials.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Several substances to test whether they are basic or acidic, e.g. lemon juice, vinegar, soap, baking powder, water, and crystal (alum) deodorants. These cause the mystery.
- Substances to explore the mystery: iron salts, aluminium salts, several deodorants (some with and some without aluminium salts, either liquid or solid), alum, red roses, raspberries, etc. Put the crystal deodorants in a beaker with water some minutes before using the solution.
- Red cabbage indicator, universal indicator, indicator paper, pH-metre, etc.
- Charts showing the colours of the red cabbage indicator and the universal indicator at different pH values.

LEARNING OBJECTIVES

Students can describe how a red cabbage indicator normally works. They learn details about anthocyanidins and realise that they form coordination complexes with aluminium and iron ions. Students learn to be sceptical and reflective about outcomes. Students learn to use different measuring devices to be sure about the outcome.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The students can determine the pH value of several substances (including crystal (alum) deodorants) using a red cabbage indicator and a universal indicator. The universal indicator suggests that the crystal deodorant reacts as an acid, whereas the red cabbage indicates a different result. It suggests that the deodorant reacts as a base. The students get tripped up while checking the pH-values of different substances as a result of this discrepancy. The teacher has to be attentive to the moment when the students come across the mystery.

Explore

COLLECT DATA FROM EXPERIMENTS

After discovering the discrepancy between the two indicators when testing the crystal deodorant, the students construct a hypothesis about which indicator is right. Which indicator do they trust more and why? The students have to collect as much evidence as possible to support the hypothesis. By experimenting with the two indicators, the students get their first ideas of the reason behind the phenomenon.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Red cabbage contains cyanidin, which belongs to the group of anthocyanidins and is responsible for the colour of the red cabbage indicator.

Anthocyanidins form coordination complexes with aluminium, boron, or iron ions (deodorants often contain aluminium ions), which causes the bluish violet colouring. This colouring is not caused by a specific pH-value, but rather by an extended mesomeric effect.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Students could test if red berries or other red or blue parts of plants also react like red cabbage (e.g. grapes, bilberries, blackberries, blueberries, cherries, cranberries, elderberries, hawthorns, loganberries, acai berries, and raspberries). Cyanidin can also be found in other fruits, such as apples and plums, and in red radishes and red onions.

Students could also investigate the reaction of the red cabbage indicator with other metal ions. Other natural indicators could also be investigated by the students (e.g. curcuma, red roses, hydrangeas flowers, etc).

Students could also investigate bathochromic effects within organic substances used for dyeing fabric.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The students should explain the chemical background of the way in which pink hydrangea flowers turn blue by adding alum to the water which is used to water the plant. The reason is that hydrangeas flowers contain the same pigments as red cabbage. So the same complexes are formed as with aluminium and iron ions: this changes the colour of the flower to blue.

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The mystery presents itself in the engage phase when the students discover the discrepancies between the two indicators when testing the crystal deodorants.

The task of the teacher is to show interest and enthusiasm for the mysterious result. This will alert the students and guide them to the explore phase.

If you need to save the time, present the mystery. First, use the two indicators with a soap solution, then with lemon juice, and afterwards with crystal deodorant solution. The students have to check the pH-value after every step.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The starting experiment is a structured enquiry (level 1). The students systematically test the substance on their pH-value. When the mystery arises, the students have to discuss the trustworthiness of indicators.

The following experimental sequence is a guided enquiry (level 2). The enquiry skills the students can develop are planning experiments, conducting experiments, recording observations systematically, comparing results, giving priority to evidence, formulating explanations from evidence, and transferring knowledge to extended tasks.

Resources

You find more background information about the subject matter here (in German): https://roempp.thieme.de/roempp4.0/do/data/RD-01-02670

More background information about different indicators (in German): http://www.chemieunterricht.de/dc2/phph/fotom-tk-1.htm

The (un)reliable indicator

STUDENT WORKSHEET

You are able to change colours! Just follow the instructions and you will see how.

Log your ideas, observations, procedures, and results in your exercise book.

Engage

WHAT'S INTERESTING?

Task: Get together in groups of four. Two members of the group should add a red cabbage indicator to the substances available. The other two should add a universal indicator to the substances. Compare the resulting colours to the scales provided that show the colours of the two indicators to determine the pH-value.

Compare your results.
Do you agree on all points?

Explore

WHAT'S HAPPENING?

Task: If the members of your group do not agree: which result represents the 'real' pH-value? Which indicator do you trust more? Why?

Phrase a hypothesis and find as much evidence as possible to support it. You may use all the materials provided on the table.

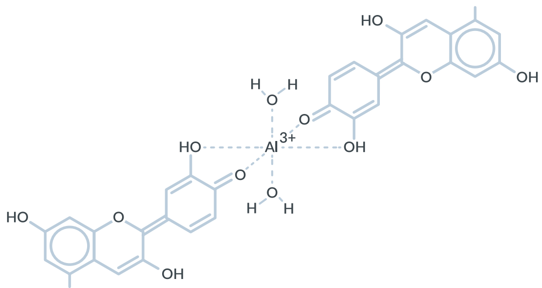
Explain

WHAT'S CAUSING IT?

Task 1: Use the Internet to find out which pigment red cabbage contains. In which class of pigment does it belong? Summarise your results in your exercise book.

Task 2: Find out why the colour of the red cabbage indicator changes when you add acidic or basic substances.

Task 3: For secondary school students: have a look at the following molecular structure. Discuss it with your group members and use it to try to explain the mystery.



Extend

WHAT'S SIMILAR?

Task 1: How does red cabbage indicator react with other metal ions (e.g. boron ions, iron ions, etc.)? Investigate whether they produce the same or a similar effect.

Task 2: Search the Internet for more objects which contain the same pigment as red cabbage.
Write at least five of them in your exercise book.

Task 3: Search the Internet for other natural indicators. Test which colours they produce when you add basic, neutral, and acidic substances to them.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: It is possible to change the colour of pink hydrangea flowers to blue. This can be done by adding alum to the water, which is used to water the plant.

Explain what happens and how this procedure works using the knowledge of chemistry you've just gained.

The Book of Science Mysteries

To dissolve or not to dissolve...

What's the mystery?

Two glasses are half full of clear liquid. When a teaspoon of salt is added to both and stirred, it dissolves in one but not in the other. When the two liquids are mixed together, they dissolve in each other to form a solution. When salt is added, the solution separates into two layers.

DOMAIN(S)

Chemistry.

SUBDOMAIN KEYWORDS

Solubility, ionic salts, polarised and non-polarised liquids.

AGE GROUP

Junior secondary (**11** to **15** years) or senior secondary (**16** to **18** years), depending on the level of explanation.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
15 min.
Approximate time in classroom:
One double lesson (**70** to **90 min.**).

SAFETY/SUPERVISION

The chemicals used are safe. One liquid is flammable, so there should be no naked flames. The solvent should be disposed of as an organic solvent. Eye protection should be worn.

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PREPARATION AND LIST OF MATERIALS

» 2 x 250 ml beakers, water (200 ml).
» Propan-2-ol (isopropyl alcohol) (200 ml) (also known as rubbing alcohol)
» Sodium chloride (3 x 5g)
» Stirrer
» Measuring spoon
» A large 400 ml beaker
» Access to other common ionic salts and solvents and laboratory equipment.

LEARNING OBJECTIVES

The importance of the nature of the solvent in solubility. The solubility of ionic salts like sodium chloride in water compared to its solubility in an organic solvent. What factors affect solubility of a salt in a solvent.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

The teacher sets up two beakers, each half full with a clear liquid. One contains water and the other beaker contains propan-2-ol (isopropyl alcohol, rubbing alcohol). A teaspoon of sodium chloride (salt) is added to both and stirred. The salt dissolves in one liquid (water) but not in the other (propan-2-ol). Why is there a difference? Why does salt dissolve in water? Why does salt not dissolve in the other liquid? The two liquids look the same but are they?

When mixed separately, the two liquids dissolve in each other and form one layer, a solution. However, when salt is added and shaken, the liquids separate out into two layers. They mix and then they separate.

Explore

COLLECT DATA FROM EXPERIMENTS

How much salt will dissolve in the water? Working in pairs, the students can repeat the above experiment while also seeing how many teaspoons of salt will dissolve in a fixed volume of water. Does the other liquid dissolve a small amount of salt or none at all? How can they tell that the two liquids are not the same?

They could smell them: water has no smell while the other liquid has a distinctive smell. They could measure the density of each by weighing equal volumes of each liquid. One liquid satisfies the characteristic test for water (anhydrous copper sulphate). One liquid does not burn and the other does. When the mixture separates into layers, how can you tell which layer is which?

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Why does salt dissolve in water and not in the organic solvent? Salt is an ionic substance composed of a lattice of sodium and chloride ions. Water molecules are strongly polarised and can pull the positive and negative ions into solution by bonding to them (use diagrams or animation to explain this). The organic liquid is less polarised (how could you show this?) and does not bond strongly enough to the ions to break the ionic bond in the solid. Use molecular models to show where the polarity comes from (the –OH groups). The polarity of water and the organic solvent can be compared by using a charged plastic comb or pen to see how much a stream of liquid from a burette is deflected. Polar liquids are attracted to the charged comb or pen: the greater the polarity, the greater the deflection. Water is more polarised than the organic solvent.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Is this behaviour shown by other ionic salts? Try some other salts in water and the propan-2-ol. Sucrose (sugar) dissolves well in water, but it is not an ionic substance. Does it dissolve in propan-2-ol or not? Does sucrose dissolve in water in a similar way to sodium chloride? Sucrose molecules are also strongly polarised and so they bond to water molecules. Propan-2-ol is not polarised enough to do this. Is sodium chloride soluble in more polarised alcohols like methanol or ethanol? Using salt to separate two miscible liquids is known as 'salting out'. Salting out is used in the production of soap.

Water and propan-2-ol mix with each other to form a solution. When salt is added and the mixture is stirred or shaken, it separates into two layers. Why does this happen when salt is added?

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Either in their own words, by using a diagram, or by making a short animation using a mobile phone, the students should describe how water molecules break up the structure of sodium chloride and bring the ions into the solution. Why do some ionic salts dissolve in water while others do not? The bonding energy of water molecules to the ions has to be stronger than the bonding energy between the ions in the solid; otherwise, the water cannot pull the ions into solution.

Propan-1-ol molecules are less polarised than water molecules and do not bond as strongly to ions; thus, they cannot break up the sodium chloride structure.

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

What would a universal solvent be like? What would you put it in? Do all liquids behave in the same way as water? I have two clear liquids here (use the same volume of each), one of which is water. What happens when I add a teaspoon of sodium chloride (salt) to each and stir? Which one do you think is water?

When I mix the two liquids together separately, they mix with each other and form a solution. Add some food colouring to colour the solution (mixture). What happens now when I add salt to the solution and shake or stir? Wow! Now why did that happen? Is that what you expected? What do you think is in the two layers? If more salt is added, does this affect the degree to which the liquid separates into layers?

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Demonstrated enquiry (level 0): the teacher does it.

The teacher introduces the mystery and asks questions. Why do some substances dissolve in water and not others? Why do some substances dissolve in water and not in another liquid (solvent)? What would a universal solvent look like? What would you put it in?

Structured enquiry (level 1): 'we do it'.

How much salt dissolves in a fixed amount of water? What sorts of substances dissolve in water? Sucrose dissolves in water: does it dissolve in the other solvent? How could you test for and identify the two solvents (smell, density, burning)? Do all organic solvents behave like the first one? Is there anything in common in the structures of those substances that dissolve in water and those that don't? How could we measure the solubility of different substances in water and other solvents? How can two liquids mix to form a solution and then separate out into two layers when salt is added? Which liquid is at the top and why? Can you explain what is going on in terms of molecular and crystal models and the charges or polarity of the particles involved? How useful is the maxim 'like dissolves like' in explaining your results?

Structured enquiry (level 2): 'they do it'.

Devise experiments to investigate which liquids dissolve in each other and how this relates to their chemical nature. How could you compare the polarity of these liquids? Investigate how the nature of the solvent affects the solubility of different solids, such as sodium chloride, sucrose, urea, and paraffin wax. What generalisations can you make about solubility and the natures of the solvent and solute?

Resources

There are a number of YouTube videos showing how the addition of salt causes the two liquids to separate out. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> separation of ethanol and water with salt

There are many animations of the solubility of salt in water. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> how water dissolves salt

The polarity of liquids can be shown using a charged plastic comb or pen and a stream of water or the other liquid. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> polar and non polar molecules static electricity demo

To dissolve or not to dissolve...

STUDENT WORKSHEET

You are familiar with how sodium chloride (salt) and sucrose (sugar) dissolve in water. However, not everything dissolves in water: flour doesn't and neither does chalk (limestone). Do salt and sugar dissolve in other liquids or is water special? Why doesn't everything dissolve in water?

Engage

WHAT'S INTERESTING?

Task: Why does salt dissolve in one clear liquid but not the other, although they look the same? The two liquids also dissolve in each other to form a solution (one layer). But when salt is added and shaken, it dissolves and the solution separates into two layers. Which layer does the salt dissolve in? Why does this happen?

Explore

WHAT'S HAPPENING?

Task: Are the two liquids the same? How do they differ? How would you identify them? How much salt can dissolve in the first liquid? What sort of liquid is the second liquid? Does salt dissolve in other similar liquids? Why does the salt cause the two liquids to separate out? How much salt is needed to do this? Does the amount of salt added affect to extent to which the liquids separate?

Explain

WHAT'S CAUSING IT?

Task: The teacher will give you the structure of the molecules in the two liquids. Make models of them or draw diagrams. Which part of the molecules will be negative and which positive? Draw a diagram of a sodium chloride crystal or make a model of it. How will the molecules interact with the solid (hint: opposite charges attract). Show how bonding between the solvent molecule and the ions in the crystal can break up the crystal and bring the ions into solution. Why is the first solvent better than the second at doing this? Set up two burettes: fill one with water and the other with the other liquid. Rub a plastic comb or pen on your hair or on a jumper to charge it. Open the burette to let a steady flow of liquid out: how is the stream affected when you bring the charged comb or pen near? Do the two liquids behave in the same way?

Extend

WHAT'S SIMILAR?

Task 1: The separation of the two liquids when salt is added is a process known as 'salting out'. Look up where this is used to make an everyday product (which you may have done already). Do other solvents behave in the same way? Does the solubility of sodium chloride depend on the type of solvent or are they all the same? Do other salts (e.g. copper (II) sulphate or sodium carbonate) behave in the same way?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Explain in words and by using a model or an animation made on your smart phone the process involved when a salt like sodium chloride dissolves in water. Explain why the nature of the solvent affects the solubility of salts. Why does sucrose dissolve in water but flour doesn't? If 'like dissolves like', why do some ionic salts (like limestone) not dissolve in water? Why does the addition of salt cause the water and organic solvent to separate out? If you have made soap in chemistry class before, how does today's lesson explain the 'salting out' of soap (if you haven't already done this, look it up)?

A flower hidden by the cold

What's the mystery?

A toy balloon filled with air is immersed in liquid nitrogen and the air seems to disappear: the balloon shrinks completely. The air seems to have disappeared.

DOMAIN(S)

Physics.

SUBDOMAIN KEYWORDS

Phase transitions, gas laws.

AGE GROUP

12 to **18** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
One hour.

Approximate time in classroom:
Three or **four** individual **50 min.** lessons.

SAFETY/SUPERVISION

Liquid nitrogen requires local health and safety precautions and pupils should be supervised at all time during its use.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» Dewar with liquid nitrogen
» Toy balloons
» Air pump
» Toy balloon filled with helium gas
» Cryogenic gloves
» Syringes with one end plugged
» Temperature sensor
» Weights
» Supports for syringes
» Electric hotplate
» Thermal cups
» Glycerol
» Graduated cylinder (at least 60-70 cm height)
» Thin plastic tube (usually used for aquariums).

LEARNING OBJECTIVES

» Qualitative graphical representation of a certain thermodynamic variable in the function of another: in particular, representation of the volume of a gas as a function of the temperature or pressure.

» Introduction to phase transitions.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

This phase has to be prepared a few minutes before the lesson. Inflate two or three toy balloons and put them in liquid nitrogen gently closing their aperture with a clamp. Then extract them, let them to swell up again, open their aperture, allow them to deflate, and finally close them with a knot. Inflate a toy balloon (of a different and recognisable colour, e.g. red), close it with a knot, and then put it in the liquid nitrogen together with the other balloons you just closed. Do the same thing with a toy balloon shaped like a flower: a long thin balloon can be used for this, since this kind of balloon can be twisted into a flower shape. You can start the lesson by extracting the empty balloons first, which will not swell, and then the balloon of the recognisable (red) colour, which will swell. What is the reason for this different behaviour? Extract the flower-shaped balloon to conclude the presentation of the mystery.

Explore

COLLECT DATA FROM EXPERIMENTS

Insert the balloon in liquid nitrogen and let the students observe what happens to the volume. The experiment can be interrupted at subsequent steps and students may make some qualitative observations about the progressive reduction of the balloon volume and the appearance of a liquid air drop.

Moreover, students may continue their investigation with syringes. One end should be plugged (melting one end with a flame, for example) and the syringes should be filled with air and put in beakers filled with some water: it is possible to study the volume variation of the air inside the syringe when the water (and also the gas) temperature varies, but not the pressure.

It is then possible to investigate the behaviour of a toy balloon filled with helium and immersed in liquid nitrogen; in this latter case, the volume will be reduced, but no phase transition will take place.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

This mystery can trigger off a discussion about the behaviour of gas and its relation to temperature. Moreover, it is possible to note a phase transition when the balloon is filled with air, but not when it is filled with helium.

Students first have to explain that the gas inside the balloon cannot be a consequence of a chemical reaction: then they can relate the volume of the gas to its temperature. Using the balloon filled with helium, they can appreciate the qualitative behaviour of the volume in relation to temperature. With the balloon filled with air, the teacher can also describe what happens in a phase transition from gas to liquid. It is possible to achieve a quantitative explanation after having read textbooks or after a discussion within the class.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

This phase can initially stimulate reflection about the relation between the volume of a gas and its pressure. This can be done using a cylinder filled with glycerol from the bottom: small air bubbles are released into this via a syringe connected to a thin plastic tube, with the other end inside the bottom of the cylinder.

It is also possible to investigate more quantitatively the relationship between the volume of a gas and the pressure: this can be carried out by means of a plugged syringe filled with air and kept vertical by a support. An increasing number of weights should be placed on its top.

Further extensions may relate to the definition of absolute temperature, a statement of the general law of perfect gas, and the differences between a perfect and a real gas.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The present mystery is principally useful for stimulating a qualitative form of reasoning among students. Therefore teachers can evaluate students during oral interviews in which pupils have to state what they can and cannot deduce from the experimental phase. Students can use a graphical representation of what they saw and also ascertain what elements they are lacking in order to get a more detailed representation.

Teachers may also investigate students' reasoning about the shape of the air bubbles that go up into the glycerol or do more quantitative investigations about what the students have experienced with the changing pressure on the plugged syringe (see the extend phase).

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The mystery proposed always engages students a great deal. They can be left to play with liquid nitrogen (using the due safety precautions) and become familiar with the physics of low temperatures.

It is possible to surprise students by inflating two identical toy balloons (possibly of an elongated and thin shape: it is easy to put this kind of balloon into the Dewar containing the liquid nitrogen): one will be filled with air and the other with helium. If the latter balloon is inflated with helium about two or three hours before the lesson, some of the air of the room will enter the balloon through osmosis and it will not go upwards, thus behaving in exactly the same way as the other balloon.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: tell the class how it is possible that only one of the balloons extracted from the liquid nitrogen swells while the other remains deflated.

Demonstrated enquiry (level 0).
Teacher-as-model: you show how to carry out an enquiry process which the students the copy. Explain your hypothesis and tests by 'talking aloud'. Students can record your thinking onto their hypothesiser lifeline worksheet.

Since a certain amount of care must be taken when handling liquid nitrogen, this is a mystery that could be fruitfully used in a level 0-enquiry lesson.

Moreover, the teacher will very quickly provide the solution of the mystery. This can be proposed by both extracting the balloons out of the liquid nitrogen and inserting them into the Dewar. Therefore, it will be very easy to understand the methodology and how to use the worksheet.

It is important that the teacher explains when it is and is not possible to get quantitative information from a certain experiment, because students often tend to invent graphs that represent a certain physical law.

Structured enquiry (level 1).
'We do it'. Students then use their Hypothesiser Lifeline sheet to record their own alternative ideas when the teacher asks "where does the air go?" or "where does the air come from?" Since it is likely that there will be one Dewar, personal experimentation may be a little difficult; however, the students can still participate in a class discussion. A more fruitful level 1 enquiry lesson can take place when studying the behaviour of a gas in relation to its pressure. In this case, students can be left safely with the glycerol in the graduated cylinder, observing the air bubbles that change their shape as they go up; in this step, it is possible to speak about the 'you do it' phase of the GRR.

Solving the mystery: students are led towards the explanation by using ideas about the behaviour of the volume of a gas in relation to its temperature and the behaviour of a gas in relation to its pressure.

Resources

To become familiar with the most common phase transitions, it is possible to observe what happens for water. This video shows how the phases depend on temperature. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > phase transition of water

In the following video, the dependence of the phase on the pressure is shown.
TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > pressure induced phase transition of ice

A flower hidden by the cold

STUDENT WORKSHEET

You have seen that many of the balloons extracted from the liquid nitrogen do not inflate when at room temperature; however, one behaves differently. How is this possible? Where does the air come from?

Engage
WHAT'S INTERESTING?

Task 1: Take the two inflated balloons and put them carefully in a Dewar containing liquid nitrogen. What is similar in the two cases? What is different?

Task 2: The air seems to diminish or disappear inside the balloons. Can you explain why this happens?

Explore
WHAT'S HAPPENING?

Task 1: Explore what happens to the first balloon when you insert it into the liquid nitrogen.

Task 2: Explore what happens to the second balloon when you insert it into the liquid nitrogen.

Task 3: Explore what happens inside the two balloons when you extract them from the liquid nitrogen. Hint: look sharply and quickly, because the changes in a gas are very fast!

Task 4: Explore what happens to a syringe filled with air which is plugged at one end and placed into a beaker filled with heated water.

Task 5: (Facultative) At home, explore what happens to a toy balloon filled with air when you put it carefully next to a heater or into the fridge or what happens to a packet of salad when you move it from the supermarket fridge to your car on a hot summer day. Equally, what happens to the pressure in your bike tires during summer and winter?

Explain
WHAT'S CAUSING IT?

Task 1: Describe the observed behaviour of the gas inside the balloon when the temperature of the gas changes.

Task 2: Do you have enough data to draw a graph of the volume as a function of the temperature? If not, why not?

Task 3: Write down your explanation about what is happening during the process that causes the apparent disappearance of the air inside the balloon. Compare this to what happens to the balloon filled with helium.

Extend
WHAT'S SIMILAR?

Task 1: What happens to the volume of a gas when its pressure changes? Try with a syringe with one end closed by glue.

Task 2: If you have a support for your syringe and some weights that you can add to the top of your syringe, describe and represent the behaviour of the volume as a function of the pressure.

Task 3: Conduct an experiment using a graduated cylinder at least 60-70 cm height, in which you can insert a thin plastic tube with one end in the bottom of the cylinder and the other end outside the cylinder connected to a small syringe. Blow little air bubbles into the glycerol with the syringe. Describe qualitatively the shape of the bubbles.

Evaluate

WHAT'S MY UNDERSTANDING?

Task 1: Suggest or design experiments for the visualisation of other gas laws. In the present example, we have considered the qualitative relationships between the volume and the temperature and between the volume and the pressure. Can you suggest other possibilities? How can you explore them?

Task 2: Since the experiments might be too challenging from a practical point of view, you can limit yourself to designing experiments.

Closer but colder

What's the mystery?

Because of the shape of the Earth's orbit around the Sun, it is farther away from the Sun in July than it is in January. Still, we have colder days in January than in July. How is this possible?

Through this mystery, students will investigate the orbit of the Earth around the Sun and its influence on solar energy here on Earth. This will lead them to a deeper understanding of the seasons on Earth.

DOMAIN(S)

Physics, mathematics, earth sciences, astronomy.

SUBDOMAIN KEYWORDS

» Physics:
(Radiative) energy

» Mathematics:
(Spherical) geometry

» Earth sciences:
Seasons

» Astronomy:
Solar radiation
Celestial mechanics

AGE GROUP

12 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
15 min.

Approximate time in classroom:
Two 45 min. lessons.

SAFETY/SUPERVISION

No need.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

The teacher should watch the following videos, which explain the reason for the seasons. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> Earth's Tilt 1
playlist> Earth's Tilt 2

Materials:

» Terrestrial globe

» Lamp/flashlight

» Protractor (optional: the universe awareness Earth ball).

LEARNING OBJECTIVES

» Learn why there are seasons.

» Learn about solar energy on Earth and its dependence on the orbit of the Earth around the Sun.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Ask the students the following questions:

1. What season are we in right now?
2. Do you think that the Earth is now closer or farther away from the Sun?

In the summer months of the Northern Hemisphere, the most likely response from the students on question (2) will be that they think the Earth is closer, whereas in winter months they will most likely think the Earth is further away from the Sun. The fact is, however, that in July (summer month on Northern Hemisphere) the Earth is farther away from the Sun than in January. For students who live in the Northern Hemisphere, this will most likely be counterintuitive.

In this mystery we will learn how seasons work, how the Sun warms up the Earth and gain more knowledge and understanding about the orbit of the Earth around the Sun.

Explore

COLLECT DATA FROM EXPERIMENTS

To help the students explore this mystery, the teacher can guide the students through the following questions:

1. How does the Earth orbit the Sun? What is the shape of that orbit?

Answer for teacher: the Earth travels around the Sun in an elliptical orbit. Look at **IMAGE 1** on the next page for more information on the Earth's orbit.

Let the students draw the Earth's orbit on a sheet of paper.

2. Can you describe how an ellipse differs from a circle?

Answer for teacher: instead of one *centre point*, an ellipse has two *focal points*. The ellipse is shaped so that every point on the ellipse has the same summed distance to both focal points (see **IMAGE 2**). On the internet you can find several great resources that demonstrate how to easily draw an ellipse using a string, pins and a pencil.

In the next section, the students will explore the properties of the intensity of light, using a flashlight, paper and a pen/pencil.

3. How does the intensity of a flashlight depend on its angle?

Answer for teacher: the total energy output of the flashlight is always the same. If the students shine light on the paper surface at an angle that positions the light beam perpendicular to the surface, the light circle will be small and intense. The energy density (amount of energy per area) on the surface will be higher than when the students shine the beam along an acute angle.

Let the students play with this. Let them hold the flashlight at different angles: have them measure and document the angle and draw a circle (or ellipse!) around the resulting flashlight beam. They will notice that the light intensity of the projected beam will be lower when they hold the flashlight at sharper angles. By doing this, they can notice that the energy density is inversely proportional to the projected area.

4. Did you know that the Earth's rotation axis is tilted? What is the angle of the Earth's axis with respect to its orbital plane? Can you determine what is the angle of this tilt of the Earth's axis?

Answer for teacher: 23.5 degrees. Students can actually find this out by looking at a terrestrial globe, which is (almost) always tilted at a 23.5 degree angle. The students can use the protractor to measure the tilt of the terrestrial globe.

The students can now use their protractor to tilt the inflatable universe awareness Earth ball by 23.5 degrees.

The students can now move their tilted Earth ball/terrestrial globe in an orbit around a lamp to simulate the Earth orbiting the Sun. Using the knowledge they gained by exploring question (1) through (4), the students should now be able to deduce why seasons exist.

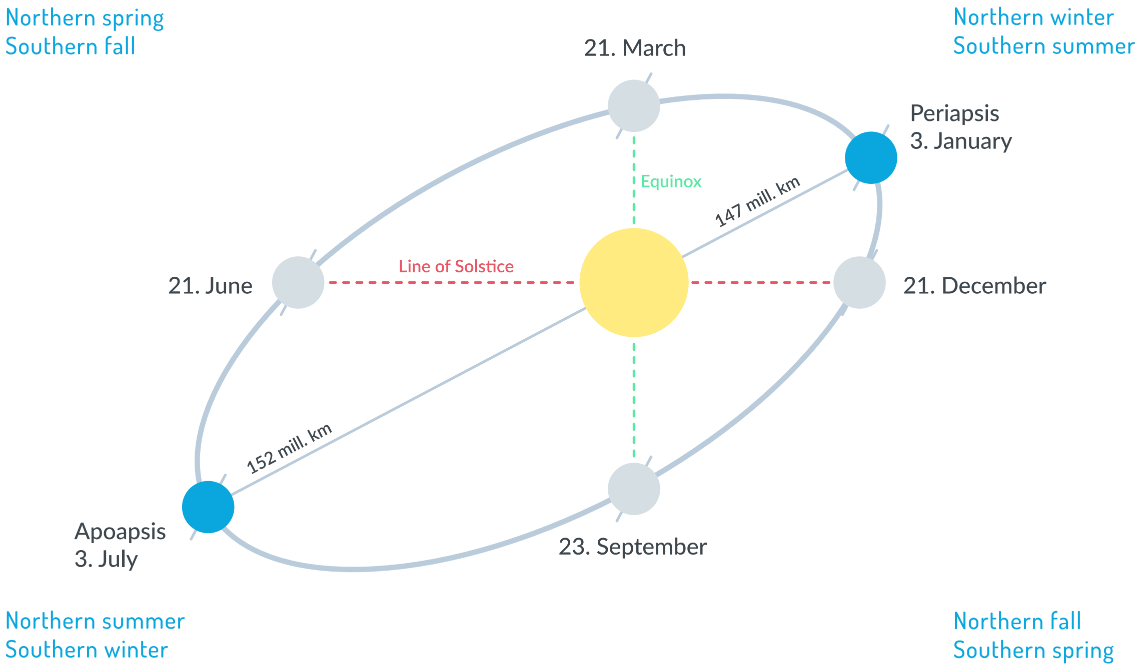


IMAGE 1. THE EARTH'S ORBIT AROUND THE SUN.
(Note that the relative sizes and distances of the Earth/Sun are not to the correct scale)

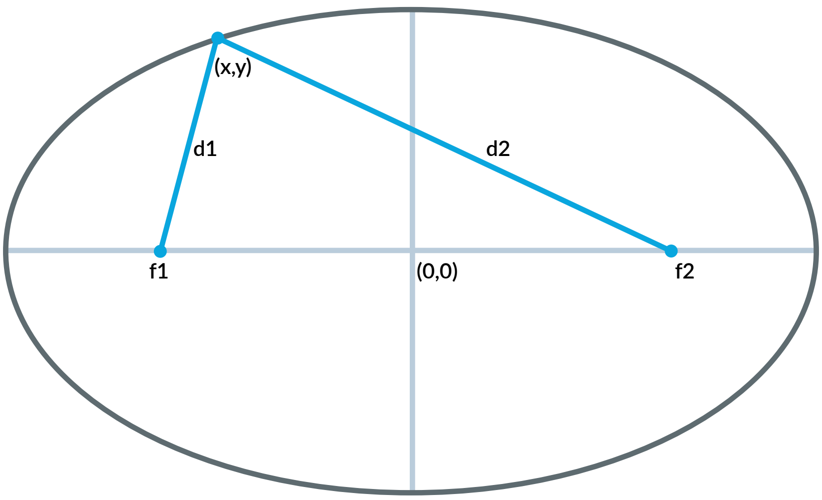


IMAGE 2. AN ELLIPSE. HERE THE SUM OF THE DISTANCES D1 + D2 IS CONSTANT FOR EVERY POINT ON THE ELLIPSE.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

At the beginning of this section, the teacher can hand to the students the diagram of the Earth's orbit around the Sun (**IMAGE 1**). It is up to the teacher to decide whether to show the students the different steps towards the explanation or to guide them through the steps.

1. The teacher/students rotate a tilted model of the Earth around a lamp and look at when the light has the highest impact on the northern hemisphere.

2. What percentage of the average distance between the Earth and Sun is the difference in distance between aphelion (apoapsis) and perihelion (periapsis)?

Answer for the teacher: About three per cent. The average distance between the Earth and the Sun is 149.5 million km while the difference between aphelion and perihelion is 5 million km.

Note for the teacher: the teacher can challenge older/more advanced students by making the the mystery more mathematically challenging. They can ask the students to calculate the difference in energy density (e.g. per m^2) between the aphelion and the perihelion. For this, the students need to use the formula for the surface area of a sphere: $A=4\pi r^2$ (where r is the radius of the sphere).

3. Hold the Earth model at a certain distance from the lamp and then add this percentage to the distance. Can you see a difference in intensity of the light shining on the Earth?
   There should be no noticeable difference.

4. Hold the Earth model tilted 23.5 degrees with the northern hemisphere facing the lamp and then pointing away from the lamp. Can you see a difference in the intensity of the light shining on the Earth?
   The students should notice a difference.

5. So what has the most impact on the temperature in Europe? The distance to the Sun or the tilt of the Earth's axis?
   Answer for the teacher: tilt of the Earth's axis. The northern hemisphere faces the Sun at a sharper angle in January than in July; therefore, the energy density on the northern hemisphere is lower in January than it is in July. This is the reason why it is warmer in the northern hemisphere in July than in January. The distance to the Sun has an insignificant effect on the temperature.

When the students have finished exploring for themselves, they can watch this video that explains it all. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> Earth's Tilt 1

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Now that the students understand the reason for seasons and the physics behind it, they can extend their knowledge and understanding.

For example, the students can extend this mystery by calculating the position of the second focal point in the elliptical orbit of the Earth around the Sun *(at five million km from the Sun, towards the aphelion point of the Earth's orbit).*

Another way to extend the mystery is for the students to look at the length of the days in the northern hemisphere at each part of the orbit. Which month has the longest days? (June). So at which point in the orbit should the Earth be tilted, with the northern hemisphere pointing towards the Sun? *(At the summer solstice, close to June).*

The students can explore the reason why the Sun shines both day and night during the summer north of the Arctic Circle but doesn't rise during the day (or night) south of the Antarctic Circle at that time. They can explore this with the globe and flashlight.

As a follow-up exercise, you can show this video. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> Earth's Tilt 2

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Let the students explain in pairs how the seasons work. They can use the globe/flashlight or build their own model with colour paper (like in the YouTube video).

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Although this seems like an obvious mystery, it is not as easy at it seems at first. It's best to let the students explore with the globe and flashlight so they can see for themselves how the tilt in the Earth's axis causes certain effects.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: ask the students what they know about the seasons, the orbit of the Earth around the Sun, etc.

Demonstrated enquiry (level 0): show the class how the Earth is tilted at an angle of 23.5 degrees when rotating the Sun. Show them what an elliptical orbit is. Watch both videos together. Let the students explain what they have learnt.

Structured enquiry (level 1): 'we do it'. Students then use their hypothesiser lifeline sheet to record their own alternative ideas about how the seasons work and to record their tests and conclusions regarding these other explanations.

Resources

The teacher can use the following YouTube videos for more information about the seasons:
TEMI Youtube Channel:
www.goo.gl/tUDaq5

A playful video explaining the reason for the seasons. It demonstrates how it can be summer in the northern hemisphere while it is winter in the southern hemisphere (and vice versa).
playlist> Earth's Tilt 1

A video explaining why the Sun will never rise above the horizon north of the Arctic Circle in January while it will never go under the horizon south of the Antarctic Circle (and vice versa in July).
playlist> Earth's Tilt 2

Closer but colder

STUDENT WORKSHEET

With this mystery, we will learn about the orbit of the Earth around the Sun and about the energy density of light. We will use these to deduce the reason for seasons.

Engage

WHAT'S INTERESTING?

Task 1: Do you know the dates that mark the start of each of the seasons? If not, find out!

Task 2: What season are we in right now?

Task 3: Do you think that the Earth currently is closer or further from the Sun than it will be half a year from now?

Explore

WHAT'S HAPPENING?

Task 1: How does the Earth orbit the Sun? What is the shape of that orbit?

Task 2: Draw a circle on a piece of paper. Now draw an ellipse next to it. Can you describe how an ellipse differs from a circle?

Task 3: By using a flashlight and a piece of paper, find out how the intensity of a flashlight depends on its angle. At what angle is the energy density of the light beam on the paper at its maximum?

Task 4: Did you know that the rotation axis of the Earth is tilted? Can you determine what is the angle of this tilt of the Earth's axis?

Task 5: Now move your tilted Earth model (terrestrial globe or inflatable Earth ball) in an orbit around the Sun (the lamp). When is the energy density of the lamp on the northern hemisphere the highest? At that point, what is the energy density of the lamp on the southern hemisphere?

And when is the energy density of the lamp on the northern hemisphere at its lowest?

Explain

WHAT'S CAUSING IT?

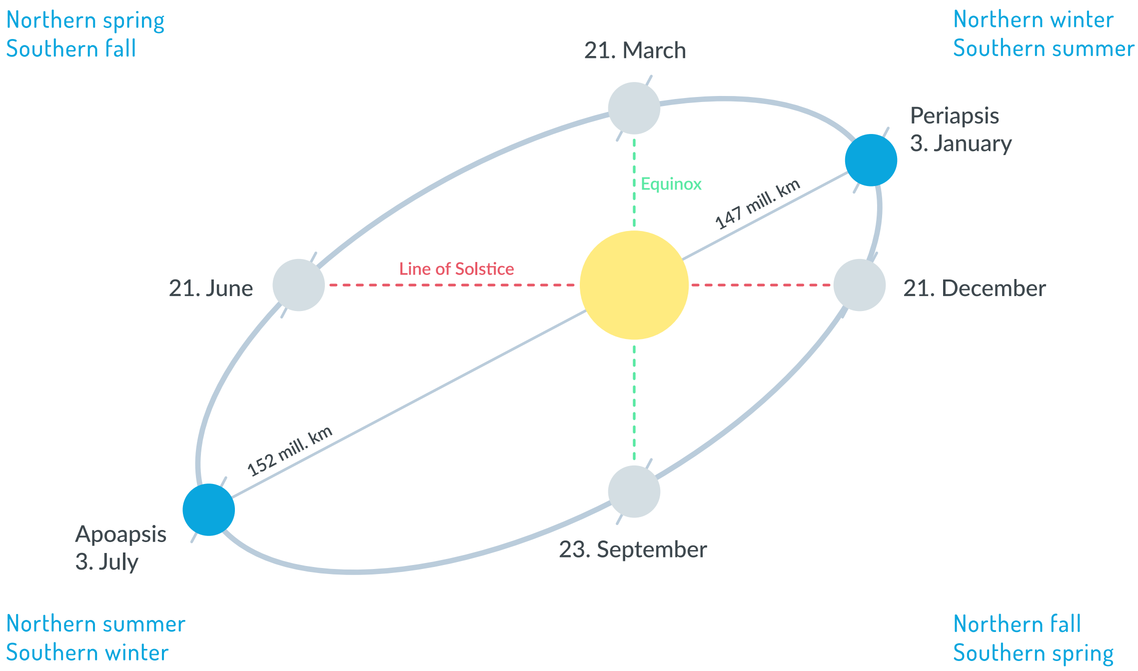
Task 1: Rotate a tilted Earth model around a lamp and look at when the light has the most impact on the northern hemisphere.

Task 2: What percentage of the average distance between the Earth and Sun is the difference in distance between aphelion (apoapsis) and perihelion (periapsis)?

Task 3: Hold the Earth model at a certain distance from the lamp and then add this percentage on to the distance. Can you see a difference in the intensity of the light shining on the Earth?

Task 4: Hold the Earth model tilted 23.5 degrees with the Northern Hemisphere facing the lamp, and then pointing away from the lamp. Can you see a difference in intensity of the light shining on the Earth?

Task 5: So what has the most impact on the temperature in Europe? The distance to the Sun or the tilt of the Earth's axis?



Extend

WHAT'S SIMILAR?

Task 1: Calculate the position of the second focal point in the elliptical orbit of the Earth around the Sun.

Task 2: Using the terrestrial globe, the flashlight, and the diagram of the Earth's orbit around the Sun, look at the length of the days in the northern hemisphere at each part of the orbit. Which month has the longest days?

Task 3: Explore the reason why the Sun shines during the night at the North Pole when it is summer in the northern hemisphere and why the Sun won't come up during the day at the South Pole. Explore this with the globe and the flashlight.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Explain what you have learnt to your classmates. Think about a good way of presenting this. For example, you can use the flashlight and globe or make your own model with coloured paper.

The Book of Science Mysteries

Face on Mars

What's the mystery?

Almost forty years ago something funny happened around Mars. NASA's Viking 1 spacecraft was orbiting the planet, snapping photos of possible landing sites for its sister ship Viking 2, when it spotted the shadowy likeness of a human face. An enormous head about 3km from end to end seemed to be staring back at the cameras from a region of the Red Planet called Cydonia.

There must have been a degree of surprise among mission controllers back at the NASA's Jet Propulsion Lab when the face appeared on their monitors. What is this enigmatic face on the surface of Mars?

DOMAIN(S)

Physics.

SUBDOMAIN KEYWORDS

Optics, Technology, Imaging, Geology, Astronomy, Planetary Sciences.

AGE GROUP

14 to **18** years old.

EXPECTED TIME FOR THE MYSTERY

45 min.

SAFETY/SUPERVISION

No need.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

Internet

LEARNING OBJECTIVES

- Learn about Mars and its surface
- Learn how images work
- Learn about image resolution
- Learn how technologies advances
- Learn some media skills, live interviewing techniques

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Back in the 70s astronomers took this picture of the region of the surface of Mars called "Cydonia". NASA scientist Gerry Soffen described it as a "trick of light and shadow".
What is this image?
What can we learn from it?

IMAGE 1. The "Face on Mars" was one of the most striking and remarkable images taken during the Viking missions to the red planet. Credit: NASA

Aks the students:

» What can you identify on it?

» What do you think astronomers thought about it at that time?

The "Face on Mars" has since the 70s been a pop icon. It has starred in a Hollywood film, appeared in books, magazines, radio talk shows –even haunted grocery store checkout lines for 25 years! Some people think the Face is *bona fide* evidence of life on Mars– evidence that NASA would rather hide, say conspiracy theorists. Meanwhile, defenders of the NASA budget wish there *was* an ancient civilization on Mars.

Students will explore this mystery through a mock-up interview. They will then discuss and present differing viewpoints about the Mars Face, using a "man on the street" TV or radio interview format. The information below will give the necessary narrative to the activity and can be used at any time to guide students through the activity.

Explore

COLLECT DATA FROM EXPERIMENTS

Although few scientists believed the Face was an alien artefact, photographing Cydonia became a priority for NASA when Mars Global Surveyor arrived at the Red Planet in September 1997, eighteen long years after the Viking missions ended.

So on April 5, 1998, Mars Global Surveyor flew over the Face and snapped a picture ten times sharper than the original Viking photos. Thousands of anxious web surfers were waiting when the image below first appeared on a JPL website, revealing … a natural landform. The "Hype" suffered a blow! There was no alien monument after all. See **IMAGE 2** on the next page.

But not everyone was satisfied. The Face on Mars is located at 41 degrees North Martian latitude where it was winter in April '98 – a cloudy time of year on the Red Planet. The camera on board MGS had to peer through wispy clouds to see the Face. Perhaps, said skeptics, alien markings were hidden by haze.

Mission controllers made preparations to look again, but it's not easy to photograph the region. The Mars Global Surveyor is a mapping spacecraft that normally looks straight down and scans the planet like a fax machine in narrow 2.5km-wide strips and it didn't fly over the Face very often.

Nevertheless, on April 2001, a cloudless summer day in Cydonia, the spacecraft Mars Global Surveyor drew close enough for a second look.

IMAGE 2. Highest-resolution view of the "Face on Mars", photographed by Mars Global Surveyor. Credit: NASA

They captured an extraordinary photo using the camera's absolute maximum resolution. Resolution quantifies how close objects can be to each other and still be seen as individual objects. Each pixel in the 2001 image spans 1.56 m, compared to 43 m per pixel in the best 1976 Viking photo!

If there were objects in this picture like airplanes on the ground or Egyptian-style pyramids or even small shacks, you should have been able to see them. And of course the image didn't look like a face anymore. What the picture actually shows is the Martian equivalent of a butte or mesa landforms, which are common on our planet. Butte or Mesa are isolated hills with steep, often vertical sides and a small, relatively flat top.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

In July 2006, the European Space Agency's Mars Express also obtained a series of images that show the famous Face on Mars located in Cydonia region. The data with a ground resolution of approximately 13.7 m per pixel.

Cydonia is littered with mesas like the Face, but these don't look like human heads and therefore they have attracted little attention from the public. Scientists have studied them carefully, however, using a laser altimeter data. The laser altimetry data are perhaps even more convincing than overhead photos that the Face is natural, rather than alien-made. 3D elevation maps reveal the formation from any angle, unaltered by clouds, lights and shadow. There are no eyes, no nose, and no mouth!

Cydonia is located in the Arabia Terra region on Mars and belongs to the transition zone between the southern highlands and the northern plains of Mars. This transition is characterized by wide, debris-filled valleys and isolated remnant mounds of various shapes and sizes.

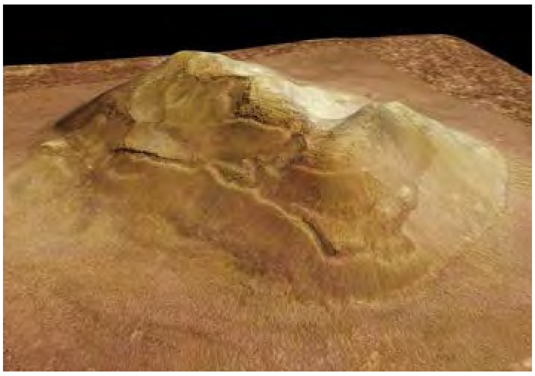


IMAGE 3. A view showing the so-called 'Face on Mars' located in Cydonia region. The image shows a remnant massif thought to have formed via landslides and an early form of debris apron formation. Credit: ESA/DLR/FU Berlin (G. Neukum), MOC Malin Space Science Systems.

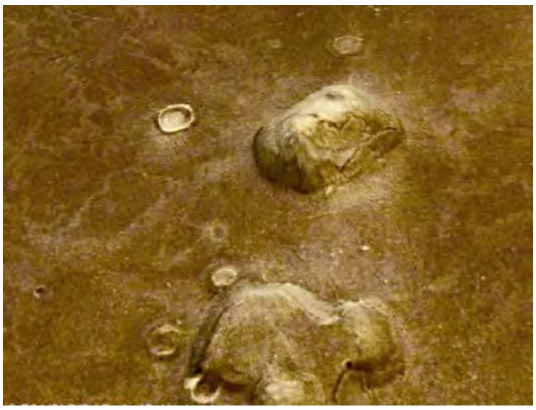


IMAGE 4. A perspective view showing the 'Face on Mars' located in Cydonia region. Credit: ESA/DLR/FU Berlin (G. Neukum)

The mesas of Cydonia are of great interest to scientists because they lie in a very interesting part of Mars. Some scientists think the northern plains are all that's left of an ancient Martian ocean. If so, Cydonia might have once been beachfront property.

The planet Mars is a special place, it reminds us of home. One day we are going to go there. That's why the Face on Mars was so popular: it reinforced that connection. But even without an alien monument, there will be plenty for future explorers to do. Climbing the mesas of Cydonia –if that's where we start– will be just the beginning.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Perhaps the best way to further unravel the mysteries of Mars would be to send a geologist to investigate. Astronomers even prepared a trail map to hike this mesa! The start and midsection of the hike would be easy, with some steep flanks in between. It would take about two hours to reach the summit of the Face. From there the view would be spectacular. To the south the ground would slope upwards, toward the highlands. To the north the terrain would descend toward the plains. Looking around you would see a barren landscape dotted with buttes, mesas, and impact craters.

Climbing to the "nose" of the Face on Mars (FoM): Starting to the SOUTH, away from the FoM, the hike begins with a walk to the scree slopes at the south base of the feature, and then moves to the right (east) around the base of the FoM, and then to the NNW up to a breach in the feature about midway through the eastern middle. At this point there is a passage up the east flank of the feature, and the hike takes this route, passing between the two ridge-like prominences that outlie the eastern "battlements" of the FoM... then the hike traverses a smoother patch before it turns and skirts the summit region before finding a circuitous path to the upper reaches of the FoM (where there is a flat, bright circular patch about 100 m in diameter).

Unmasking the Face on Mars wasn't easy! But astronomers have done it by virtue of their hard work and technology development, with better and better resolution instruments.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

To evaluate the students' understanding of the mystery, the teacher can ask the simple question: What's the Face On Mars? Students should be able to explain that this is just a geological feature similar to the Earth's small butte or mesa landforms. I.e., isolated hill with steep, often vertical sides and a small, relatively flat top.

Teachers can also ask further questions, like:

1. How did scientists explain the Mars Face in the 70s?
2. Why should you take plenty of oxygen and water if you plan to climb the Mars Face?
3. What is a mesa?
4. Where is the Mars Face?
5. Do you think that the Mars Face is exotic? Why?
6. Which is the best picture of the Face? Why?
7. Why do some people think that the Mars Face is evidence of life on Mars?
8. What is an altimeter?
9. What is resolution?

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

This is a mystery to explore. Students will discuss and present differing viewpoints about the Mars Face, using a "man on the street" TV or radio interview format.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Through the interview mock-up students will have the opportunity to explore different roles in the process of knowledge acquisition.

Resources

Teachers can show the ESA video about the region: http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Cydonia_s_Face_on_Mars_in_3D_animation

Face on Mars

STUDENT WORKSHEET

Almost forty years ago something funny happened around Mars. NASA's Viking 1 spacecraft was orbiting the planet, snapping photos of possible landing sites for its sister ship Viking 2, when it spotted the shadowy likeness of a human face. An enormous head about 3km from end to end seemed to be staring back at the cameras from a region of the Red Planet called Cydonia. There must have been a degree of surprise among mission controllers back at the NASA's Jet Propulsion Lab when the face appeared on their monitors.
What is this enigmatic face on the surface of Mars?

Engage

WHAT'S INTERESTING?

Task: First, find a person to work with. Decide who will be the reporter and who will be the person interviewed (the "interviewee").

Next, choose what background and profession the person interviewed will have. The possibilities are limitless -- scientist, barber, teacher, cosmetologist, cosmologist, rock climber, rapper, printer, physician, actor, driver, or diver! It could be anything (appropriate to your school setting of course!) Check the script outline below. You are welcome to improve it, and certainly do add the needed information and opinions. Practice it once, and then perform as requested by your teacher.

Reporter: Hello, my name is _____________ and I am speaking to you directly from ____________________. I am going to ask just a regular person on the street about that famous Mars Face.

Interviewee: Hi! Is that a TV camera? Am I going to be on TV?

Reporter: Why yes. I have a couple of far-out questions to ask you but first, can you tell the people at home your name and what you do for a living?

Interviewee: Answer.

Reporter: Great! Now, could you tell us what you think of the Face on Mars?

Interviewee: Answer.

Explore

WHAT'S HAPPENING?

Task: **Reporter:** Do you believe that the Mars Face proves that life has been on Mars?

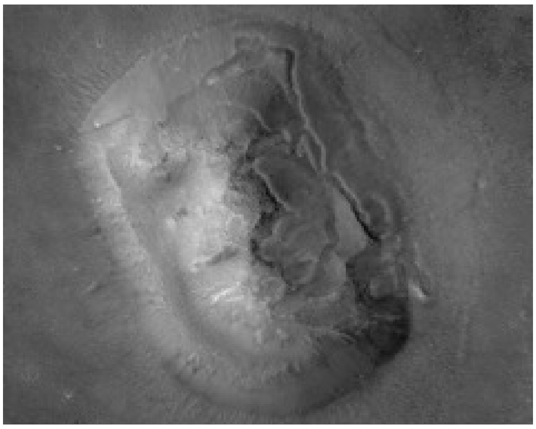
Interviewee: Answer.

Reporter: That's interesting. Why do you believe that?

Interviewee: Answer.

Explain
WHAT'S CAUSING IT?

Task: Show image:



Reporter: How would you explain the photos of the Face?

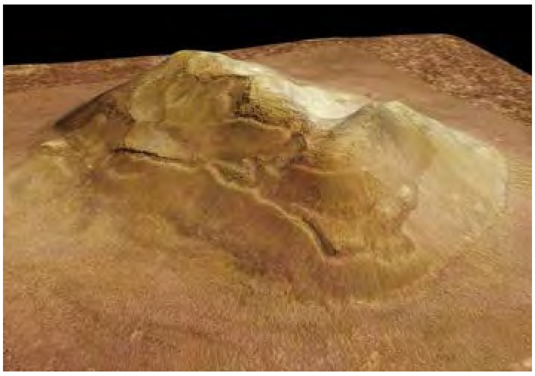
Interviewee: Answer.

Show both pictures together.
Reporter: How would you explain the difference between these 2 photos of the Face on Mars?

Interviewee: Answer.

Extend
WHAT'S SIMILAR?

Task: **Reporter:** Look at this more recent image. Do you find any similarities?



Interviewee: Answer.

Evaluate
WHAT'S MY UNDERSTANDING?

Task: **Reporter:** So, in the end, what do you think is this "Face on Mars"?

Interviewee: Answer.

The Book of Science Mysteries

Field trip with ghosts?

What's the mystery?

A group of students are spending the night in a cabin. After preparing some food, they suddenly hear a strange noise from the kitchen: a can of oil has fallen down from the oven and something or someone has crushed it. Some of the students think that there is a ghost in the cabin.

DOMAIN(S)

Physics, Chemistry.

SUBDOMAIN KEYWORDS

Temperature, force, particles, atom, pressure, gas, phase transition, kinetic energy.

AGE GROUP

13 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
One hour.

Approximate time in classroom:
Two hours.

SAFETY/SUPERVISION

Remember safety when working with butane burners.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Butane burners
- Tripod
- Beaker
- Matches
- Soda cans.

LEARNING OBJECTIVES

Think critically about experiments. Learn about atmospheric pressure, balancing forces, the fact that temperature is a measure of particle velocity, and kinetic energy.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

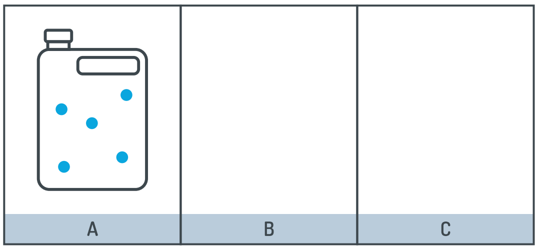
It was an unusually cold autumn day, with frost and snow covering the ground. A group of friends made an overnight trip to a cabin in the woods. When the evening came, and they started to make supper, they discovered that both oil and butter had been left at home. While one of the girls looked around in the cabinets with the hope of finding some butter or oil, the rest of the gang sat down in front of the fireplace in the living room, eating snacks and sandwiches, and telling ghost stories. Suddenly there was a loud scream from the kitchen. The class stormed into the kitchen and found Oda terrified. However, gradually she began to laugh and explained what had happened. She had found a can with some frozen olive oil at the bottom. To get the oil, she had warmed up the can on a hot plate. After a few minutes, the lid on the jug shot off, scaring her.

One of the boys, Fabian, took a cloth and lifted the can away from the hot plate. He put the cap back on the can and they all went back to the living room. When they started telling ghost stories again, there were some strange noises from the kitchen. But now there was no one in there... They walked quietly back towards the kitchen. The oil can was lying on the floor and it looked like someone had stepped on it...Was the cabin haunted? Fabian tried to calm his friends by saying that he knew what had happened! He remembered something from science class and believed that he could convince the rest that there were no ghosts around.

Explore

COLLECT DATA FROM EXPERIMENTS

Task 1: The figure illustrates the gas molecules in the can when it was first found in the kitchen. In B, draw a picture of the collapsed can. In C, draw what would have happened if Fabian had not put the lid on when he removed the can from the hot plate.



Task 2: Go through the following statements in the table in the next page, and give them a score based on their relevance to what happened with the can (0 is not relevant, 5 is very relevant).

Task 3: Show the imploding soda can experiment to the class. Tell the students to work in pairs and hypothesise as to why the can implodes when it is immersed into cold water.

Reason why the lid popped of the can was:	Score	Scientific reasoning
The pressure increased inside the can		
The volume between the gas molecules increased		
The speed of the gas molecules increased		
There were more collisions between the gas molecules and the can		
Hot air rises		
There was a difference in pressure on the inside and outside of the can		
The can gets bigger when heated up		

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Connect the imploding soda can experiment to the ghost story.

When the girl heated the can with oil, the molecules inside the can started to move faster and faster. Since the space between the molecules increases when the temperature increases (i.e. the pressure increases) the additional force on the weakest point of the can, the lid, caused it to pop off. In this process, gas molecules escaped the can. When the lid was put on again and the can was removed from the stove, the temperature of the molecules inside the can decreased. Due to the fact that the pressure inside the can is lower than the air pressure outside it, the surrounding air pressure caused the can to implode. It is also relevant to discuss the definition of temperature. For some students, it might also be relevant introduce the formula for kinetic energy ($E=1/2mv^2$) and ask them to deduce whether the mass of the gas particles might influence pressure inside the can: would the results be different if some other liquid was present? In other words, GRR can easily be implemented in this mystery.

Relevant concepts to remember: phases, phase transitions, air pressure, implosion, force.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

In everyday life, temperature affects phase transitions (gaseous, liquid, and solid). Let the students make a list of such examples. Water is a prominent example. The process of condensation can be introduced. One everyday experience that might be mentioned is that bottles can look deformed during a flight in a jet plane. This mystery can also be extended to geology, since pressure is one of the main reasons causing formation of oil and gas in sedimentary rocks.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

During their work, the students can assess their own reasoning. By discussing the students' answers in class, the teacher can uncover misconceptions and explain the principles of the subject. At the end of the lesson, the students can work in pairs and make a quiz with questions from the subject.

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Engage:
Before telling the ghost story to the students, it might be a good idea to bring an already imploded can, which can be tossed in front of the students during the story at the point when the characters hear noises from the kitchen.

Start by dimming the light and perhaps lighting a candle to catch the students' attention. Talk quietly and slow so that everyone can grasp the content. Practise the story beforehand.

Explore:
After the students have gone through the questions, summarise the answers in class. Make sure you go through the concepts of phases, phase transitions, and the speed of molecules with respect to temperature.

Guide the students through the steps of designing the hypothesis based on what is happening with the water molecules when they are heated and what it is causing the can to implode. Instruct the students how to safely handle the butane burner.

Include a short teachers' guide to the main sequence in teaching this mystery and how they should be presented (showmanship).

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: tell the ghost story to your class.

Demonstrated enquiry (level 0): tell the students to solve the questions shown in the explore phase in pairs. When the answers have been summarised in class, perform the collapsing soda can experiment.

Guided enquiry (level 1): 'We do it'. Ask the students to hypothesise why a heated soda can collapses when it is placed into cold water. The students can make several hypotheses by testing at different temperatures or using cans made of different materials. The students can also calculate the amount of atmospheric pressure, since atmospheric pressure of at least x newtons is needed to deform the can.

Solving the mystery: students are led towards the explanation by using ideas about the particle model and how heat is related to pressure.

Resources

This webpage presents useful insights on atmospheric pressure:
www.livescience.com/39315-atmospheric-pressure.html

The mystery is adapted from the book:
Erduran, S. and Pabuccu, A. (2012). Bonding chemistry and Argument: Teaching and Learning Argumentation through Chemistry Stories, a booklet.

Field trip with ghosts?

STUDENT WORKSHEET

This is a mystery about some powerful features of nature, like pressure, forces, and the effect of temperature on air pressure.

Engage

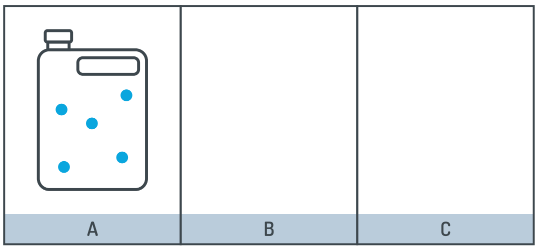
WHAT'S INTERESTING?

Task: Listen to your teacher telling the story about what happened at the cabin. What gave the can a crushed appearance? Do you believe in ghosts?

Explore

WHAT'S HAPPENING?

Task 1: The figure illustrates the gas molecules in the can when first found in the kitchen. In B, draw a model of the collapsed can. In C, draw of what would have happened if Fabian had not put the lid on the can when he removed it from the hot plate.



Task 2: Go through the following statements in the table in the next page, and give them a score based on their relevance to what happened to the can (0 is not relevant, 5 is very relevant).

Task 3: Your teacher will now perform a magic trick.

Work in pairs and hypothesise why the can implodes when immersed in cold water.

Discuss with your partner the following question: in which three forms/phases does water exist?

Explain

WHAT'S CAUSING IT?

Task: Test your hypothesis. Be careful with the butane burner. Discuss the following with your partner:

- What happens to the molecules when they change phase?
- How does the space between the molecules in each phase change with increases to the temperature?

How can you relate this experiment with the setting in the ghost story?

Extend

WHAT'S SIMILAR?

Task: Work together in pairs. Can you think of any substances other than water vapour which might be affected by temperature changes? When the temperature or pressure changes, the substance goes through a phase transition, like during springtime, when ice transforms to water which again transforms to water vapour.

Reason why the lid popped of the can was:	Score	Scientific reasoning
The pressure increased inside the can		
The volume between the gas molecules increased		
The speed of the gas molecules increased		
There were more collisions between the gas molecules and the can		
Hot air rises		
There was a difference in pressure on the inside and outside of the can		
The can gets bigger when heated up		

Think of the following materials: rocks, iron, and carbon dioxide. Use the Internet and find the temperatures where these substances experience phase transitions.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Work in pairs and make a quiz with ten questions from the topic. Solve your quiz and go through them together afterwards. At the end of the lesson, hand them in to your teacher.

Guess the colour!

What's the mystery?

The colour of the objects around us depends on the surface of the object, on the colour of the light that illuminates them, and the system of human perception. If many small pieces of differently coloured cardboard are placed under a nearly monochromatic light, it can become very difficult to distinguish the colours.

DOMAIN(S)

Physics.

SUBDOMAIN KEYWORDS

Additive and subtractive synthesis of colours.

AGE GROUP

12 to **18** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
Two hour.

Approximate time in classroom:
three or **four** individual **50 min.** lessons.

SAFETY/SUPERVISION

Laser pointers have to be handled with care and never directed towards people's eyes.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» Green and red laser pointers
» Diffraction gratings
» Coloured and white cardboards
» Green LED light
» Blue LED light
» Red LED light
» Coloured filters
» Black blankets
» Supports to be covered by the blankets (so that each group will not be disturbed by the lights being used by the other groups).

LEARNING OBJECTIVES

» To become familiar with the additive synthesis of lights and with the subtractive synthesis of the coloured pigments.
» To become familiar with how colours look under different coloured lights.

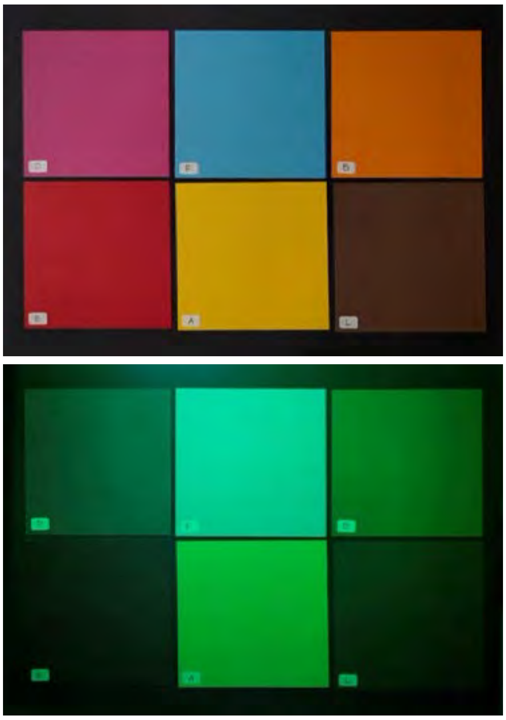
Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

When the game starts, the classroom's main light is off; at a certain point, a monochromatic light is turned on (for example, a green light). A volunteer student is asked to pick up two pieces of cardboard of different colours (the teacher has checked beforehand that these colours are markedly different under the monochromatic light being used): in the example shown in the picture, the colours are cyan and purple. Then the student inserts the pieces of cardboard into two envelopes and closes them. On the top of the two envelopes is written the name of the colour of the cardboard inside. This procedure is repeated with three different monochromatic lights. Under white light, the envelopes are opened and the students observe with surprise the 'true' colours of the pieces of cardboard they have chosen.



Explore

COLLECT DATA FROM EXPERIMENTS

Students start their observations in the darkness (each group should be independent from the others and conduct the experiment while covered with a black blanket): each group has a diffraction grating and many different kinds of lights, from monochromatic ones to incandescent ones. At the beginning of the activity, students become familiar with a monochromatic light (they can use the laser light, for example) and they can see what happens when the light passes through a diffraction grating.

In the second phase, by observing the light used and the colour observed, students should observe which colours are absorbed and which colours are reflected by an object when the object is illuminated with a certain monochromatic light. Deeping their observations, students can use two different monochromatic lights to illuminate their pieces of cardboard. The teacher may help students to choose particular pieces of cardboard to better direct their exploration.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Through observing the light used and the colour, students should recognise which of the colours absorbed are then emitted by the object (the colour of a certain object under a certain light).

It is also possible that different human eyes can see slightly or markedly different colours: this can provoke a reflection on human physiology and its connection with the problem of vision, which is not only a physical problem.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

After having mixed the coloured lights (and having therefore experienced additive synthesis), it is possible to repeat the same mixes of colours using acrylics, Ecoline, or coloured inks. This set of experiments will give completely different results from the previous one: this pigment mixing will give an example of subtractive synthesis.

It is also possible to deal with the link between the wavelength of light and colour and the fact that not all the colours we see are present in the spectrum or in the rainbow. This is a very important point that should be emphasised and discussed with the students. A very useful insight can be provided by observing spectral lamps though a diffraction grating.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

A possible way to evaluate students is by giving them problems to be solved from both theoretical and practical points of view. For example, "find a way in which a certain word, written in red on a white cardboard, can disappear" or "can you write a message whose words give two different meanings when illuminated with lights of different colours?" It may also be useful for students to pose questions of this kind by themselves.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The presentation of the mystery 'guess the colour!' is conducted via a game. It is important that the game is performed using a precise theatrical system: students must enter the classroom when the darkness has already been brought about and the three sets of coloured cardboards are placed onto a table. They should be covered with three black pieces of cardboard that will be removed one by one.

The white light of the sun or the artificial light of the room will be turned on only at the end of the game, at which point the students will learn how close their guesses are to the colour of the cardboard inside each envelope.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: perform a game with the class in which students are asked to pick up a certain piece of coloured cardboard from a set of six pieces of cardboard illuminated by a monochromatic light. Under this light, the pieces of cardboard seem to lose their colour.

Demonstrated enquiry (level 0).
Teacher-as-model: you show how to carry out an enquiry process, which students then copy. Explain your hypothesis and tests by 'talking aloud'. Students record your thinking onto their hypothesiser lifeline sheet. Since this mystery requires many steps to be solved, it is more convenient to use a structured enquiry.

Structured enquiry (level 1).
'We do it'. Students then use their hypothesiser lifeline sheet to record their own alternative ideas about the nature of white light. They can both combine monochromatic lights to get white light and divide a white light into its component via a

diffraction grating. Students have to record their tests and conclusions regarding their investigation on white lights.

In the second step, students will use again their hypothesiser lifeline sheet to investigate how the colours of the pieces of cardboard change if observed in a particular monochromatic light. They should first experience what happens when mixing inks and then what happens when illuminating coloured cardboards.

Solving the mystery:
Students are led to the explanation by using ideas about the additive synthesis of lights and subsequently about the subtractive synthesis with coloured pigments. At the end of the enquiry learning cycle, they should have a clear understanding of why, for example, the fundamental colours of a printer are magenta, cyan, and lemon yellow rather than red, green, and blue.

Resources

The first video is a 1950s educational documentary about colour. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> this is color

The following video pertains to the additive synthesis of light and the physiology of vision. In addition, it briefly discusses the fact that there is no correspondence one to one between a colour and a wavelength. TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> colour mixing

Guess the colour!

STUDENT WORKSHEET

From the game with coloured lights and coloured pieces of cardboard, you have seen that it may be very difficult to correctly pick a certain colour under a monochromatic light. To solve this mystery, it will be necessary to travel into the world of coloured lights.

Engage

WHAT'S INTERESTING?

Task: Work in the darkness if you can.

Explore

WHAT'S HAPPENING?

Task: Look at the different kind of lights through a diffraction grating, try monochromatic light and light from an incandescent bulb,. What colors do you see in each case?

Explain

WHAT'S CAUSING IT?

Task: Define the color of a cardboard as the color that appears when it is illuminated by a white light. Then, illuminate some colored cardboards with a monochromatic light. Use the red, the green, the blue and the white cardboards first, write down in a table the color of each type of cardboard when it is illuminated by the red, the green and the blue light. Can you find any pattern?

Extend

WHAT'S SIMILAR?

Task: Now, illuminate each cardboard with a couple of different lights at the same time, use all the possible combinations of colors. Write down your observations in a table.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Work in pairs and make a quiz with ten questions from the topic. Solve your quiz and go through them together afterwards. At the end of the lesson, hand them in to your teacher.

The Book of Science Mysteries

Red Moon

What's the mystery?

When the Moon travels through the Earth's shadow, sunlight is blocked. However, instead of turning completely dark, the Moon gets a reddish colour. How is this possible?

DOMAIN(S)

Physics.

SUBDOMAIN KEYWORDS

Astronomy, optics, propagation of light.

AGE GROUP

16 to **18** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time in classroom:
two **45 min**. lessons.

SAFETY/SUPERVISION

No need for safety measures.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» Internet (for YouTube)

Experiment 1. Dispersion and refraction:

» White flashlight (not LED)

» Prism

» Glass of water, straw

Experiment 2. Scattering of light:

» White flashlight (not LED)

» Large transparent container of water (~10 l)

» Cup of whole milk (not skimmed)

LEARNING OBJECTIVES

» Learn about the light scattering properties of the atmosphere.

» Learn about the refracting properties of the atmosphere and other mediums.

» Learn why the day sky is blue.

» Learn why the sky turns red during a sunset.

» Learn why the Moon turns red during a lunar eclipse.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

During a solar eclipse, the Moon passes between the Sun and the Earth: the Moon blocks the sunlight from illuminating a small part of the Earth, turning it dark.

During a lunar eclipse, the Moon passes directly behind the Earth into its shadow (which is known as the *umbra*). This can only occur when the Sun, Earth, and Moon are aligned with the Earth in the middle. Even though the Earth blocks all the sunlight from illuminating the Moon, the Moon doesn´t turn completely dark. Instead of becoming totally black, the Moon turns red!

Of which natural phenomenon does this reddish colour remind you?

Hint for the teacher: guide the students towards thinking about a red sunset. Show the students pictures of a lunar eclipse. Examples:

» The 4 April 2015 lunar eclipse over Melbourne. Credit: Scott Cresswell. License: CC Attribution 2.0 Generic. https://flic.kr/p/rWR4eD

» Sunrise over Los Angeles on 11 December 2011. Credit: Michael R. Perry. License: CC Attribution 2.0 Generic. https://flic.kr/p/aTf6QV

Explore

COLLECT DATA FROM EXPERIMENTS

Start out by asking the students to make a sketch of what happens during a lunar eclipse: this sketch should contain the Sun, Earth, and Moon, the sunrays, and the shadow of the Earth (obviously the scales don't need to be correct). The Moon should be inside the Earth's shadow (see **IMAGE 1**).

How is it possible for the Moon turns red during a lunar eclipse rather than black?

At this stage, the students should explore the refractive and scattering properties of white (Sun) light through different mediums. The following experiments can be performed by the teacher/ students to gain more insight into these properties. In these experiments, the role of the teacher is very important for guiding the students in the right direction. Depending on the level of the students, the teacher can decide to only give a short introduction to each of the experiments and let the students find out the rest (with guidance if needed) or to walk the students through all the steps of the experiments.

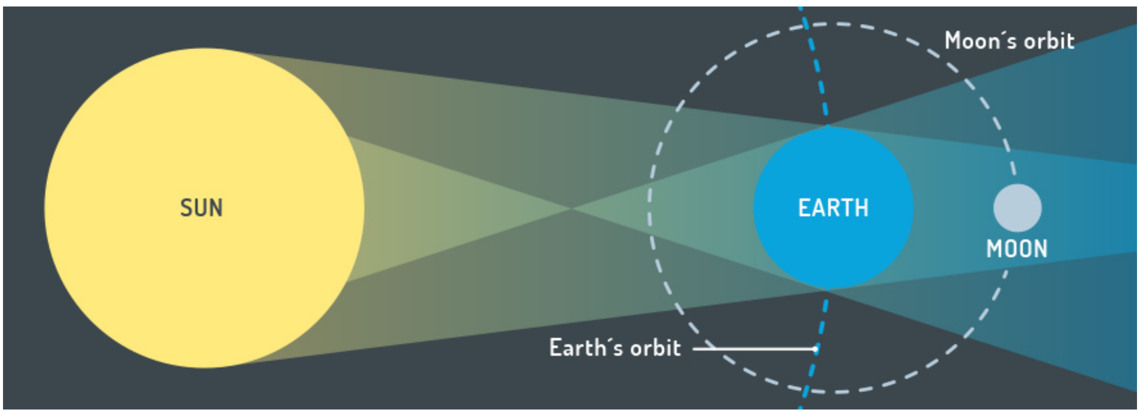


IMAGE 1. What happens during a lunar eclipse?

Experiment 1.
Dispersion and refraction of (white) light.

By using a white light source and a prism, the students can see that white (sun)light is in fact a combination of lights of different wavelengths on the visible electromagnetic spectrum. Furthermore, this experiment shows students that as a ray of light passes from one medium into another, the direction in which the ray propagates will change: the ray of light will “bend”, a natural phenomenon known as *refraction*. What should really stand out for the students is that the amount of refraction is not only dependent on the type of medium, but also on the colour (i.e. the wavelength) of the light. This difference in the angle of refraction for different colours of light is known as *dispersion*. The most commonly known example of dispersion is the appearance of a rainbow.

There are a lot of ways to demonstrate refraction, even with very basic material. A few examples can be found in the following videos:

» Using refraction to “bend” a straw.
TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> refraction in water

» Using refraction to reverse text.
TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> amazing water trick

The following questions may help the students at this point reach a better understanding:

1. Sunlight consists of all the colours of the rainbow. In what order do you see the colours in a rainbow?

2. When looking at the point where the beam of light enters the prism, what happens to the direction of the beam of light?
Answer for the teacher: *the beam of light bends due to refraction!*

3. Can you name some everyday examples where you have witnessed the refraction of light?
Answer for the teacher: *for example, when you are standing in a swimming pool and look at your feet or when looking at a straw in a glass of water.*

4. What is the difference between the refraction of red light and the refraction of blue light?
Answer for the teacher: *red light has a longer wavelength than blue light. By using the prism with white light, the students will see that blue light gets refracted more strongly than red light. The students can conclude from this that the power of refraction will decrease with increases in wavelength.*

5. Can you think of another factor besides the type of media which influences the amount of refraction?
Answer for the teacher: *the colour (i.e. the wavelength!) of the ray of light.*

Experiment 2.
Scattering of white light.

When light passes through transparent material, it can get scattered by particles (atoms or molecules) in the material that are much smaller than the wavelength of the ray of light. This phenomenon is called *Rayleigh scattering*. This type of scattering has a very strong wavelength dependence ($\sim\lambda^{-4}$), which results in blue light (shorter wavelength) being scattered far more strongly than red light (longer wavelength). This is also the reason for our blue sky: the blue light in sunlight gets scattered much more by the molecules in the atmosphere than the red light. In whatever direction you look in the sky, you will see the blue light.

Rayleigh scattering can be demonstrated using a flashlight, a large transparent container of water (~10 l), and a ¼ cup of whole milk. By adding a bit of the milk to the water, you create a situation similar to that of the molecules in the atmosphere.

The students can hold the flashlight to the side of the container so that its beam shines through the water. Let the students explore what happens to the colour of the light beam. Let them experiment by adding more milk or by positioning the beam of light in such a way that it has a longer/shorter trajectory through the water. What happens to the colour of the beam? Can the students create a setup that results in a bluish colour or a yellow/red colour?

» The following video shows an overview of the possible results that the students might get.
TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist> create a sunset

After this experiment, the teacher can ask the following questions to the students:

1. Can you now explain why the sky is blue?

2. Can you now explain why the sky turns red during a sunset/sunrise?
Answer for the teacher: *at sunset, the sunlight we observe has to travel a much longer distance through the atmosphere than at noon. Therefore, there is much more scattering; by the time the light reaches your eyes, most of the blue light (as well as green and violet light) has been scattered and diffused away, leaving the yellow, orange, and red light, which is much less affected by the scattering.*

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

In order to explain the mystery, we must now apply what we have learnt about refraction, dispersion, and the scattering of light to a lunar eclipse.

The teacher can guide the students through the following questions:

During a lunar eclipse, the Earth will block all sunlight from directly reaching the Moon; however, what effect will the Earth´s atmosphere have on the sunlight?

Which colour can best travel through the atmosphere?

Draw a diagram of what happens during a lunar eclipse: can you, with all the knowledge you now have of refraction, dispersion, and scattering, explain why the Moon is red during a lunar eclipse instead of completely dark?

At the end of this phase, the teacher can summarise the mystery for the students and provide them with an overview.

This mystery has everything to do with scattering and refraction. Sunlight is composed of all the colours of the rainbow, as you can see with the help of a prism. Each colour has a different wavelength, much in the the same way that the frequency of a musical note distinguishes it from the other. Each of these colours in the sunlight gets scattered and refracted differently according to their wavelength.

The sky is blue because of the scattering effect of the atmosphere on sunlight. The shorter the wavelength of a colour, the more it gets scattered. Blue has the shortest wavelength of all visible colours, so it gets scattered the most. Therefore, blue seems to come from all directions of the sky, whereas red and yellow light (longer wavelengths) only seem to come from the direction of the Sun.

A sunset is red because scattering is most extreme when the Sun is near the horizon. This is because the sunrays need to cover a much longer distance through the atmosphere to reach our eyes. Now the blue, violet, and green light in the sunlight gets scattered away and seems to come from other directions. The colour red has the longest wavelength and therefore experiences the least scattering; it is the only colour that is left coming from the Sun´s direction. All the other colours look as if they are coming from all directions. In this way, the horizon surrounding the Sun looks red. These phenomena play a big role during a lunar eclipse.

During a lunar eclipse, the Earth moves between the Sun and the Moon, blocking the light from Sun from directly reaching the Moon. However, some sunlight gets refracted twice by the Earth's atmosphere (refraction during the transition from space to Earth´s atmosphere and again from the Earth´s atmosphere back into space) as it travels around the curve of the Earth towards the Moon. During this journey through the atmosphere, all the colours that make up sunrays except red get scattered, thus never making it to the Moon. They get trapped inside the atmosphere. Red experiences the least scattering and thus is the only colour that makes it through the atmosphere to reach the Moon: hence the red Moon! From the point of view of the Moon, the Earth looks like a dark disk surrounded by a red glowing ring.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Scattering and the diffraction of light through different lenses or colour filters.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

To evaluate the students' understanding of the mystery, the teacher can hand out the questionnaire on the student worksheet under "evaluate".

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The main difficulty with this mystery is that, in order to solve it, the students first need to understand several key aspects of refraction, dispersion, and the scattering of light in different scenarios. This can make it hard for the students to find out the reason for the red moon by themselves. In this mystery, the role of the teacher is therefore very important.

In order to understand this mystery, it can be very helpful for the students to visualise what is happening. This can be done by showing pictures and movies or by letting the students draw what happens during a lunar eclipse (position of the Sun vs. the Earth vs. the Moon) and how the light can and will travel in this scenario.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

The explain and explore parts can be done simultaneously. The teacher asks a question and will explore the answer together with the students. It would help to show the YouTube video beforehand. Thus, the students will get to know a bit more before exploring the issue themselves.

Resources

The teacher can watch the following video on the TEMI Youtube Channel:
www.goo.gl/tUDaq5

playlist> why the Moon is red during a total Lunar eclipse

Red moon

STUDENT WORKSHEET

During a solar eclipse, the Moon passes between the Sun and the Earth: the Moon blocks the sunlight from illuminating a small part of the Earth, making it dark. During a lunar eclipse, the Moon passes directly behind the Earth into its shadow (which is known as the ?umbra?). Even though the Earth blocks all of the sunlight from the Moon, the Moon doesn?t turn completely dark. Instead of becoming totally black, the Moon turns red. Which natural phenomenon does this reddish colour remind you of?

Engage

WHAT'S INTERESTING?

Task: Circle the lunar phase(s) when a lunar eclipse can occur:

- » New Moon
- » First Quarter
- » Full Moon
- » Last Quarter

Explain why a lunar eclipse can only occur during this/these lunar phase(s) with a sketch (hint: make sketches with a top-down view of the Sun/Earth/Moon during each of the lunar phases).

Explore

WHAT'S HAPPENING?

Task 1: First, start by making a sketch of what is happening during a lunar eclipse: what is the position of the Moon compared to the Earth and the Sun? What happens to the light from the Sun as it tries to reach the Moon?

Now, let's explore some properties of (white) light by doing some experiments:

Experiment 1. Colours and bending of (white) light.

You probably know that "white" sunlight is actually made up of all the colours of a rainbow.

By using of a white flashlight (preferably with a very tight and dense beam) and a prism, you can disperse white light; that is, break up the white light into its spectral components (i.e. the colours of the rainbow). Now look at these different colours more closely:

1. In what order do you see the colours in the rainbow?

As you know, light moves on a straight line when it travels through the air. Now look very closely at the point where the beam of your flashlight enters the prism.

2. What happens to the direction of the beam of light?

As the ray of light passes from one medium (in this case: air) into the other (the glass of the prism), the ray of light will bend! Once the light has crossed the boundary between the two media, it continues to travel in a straight line again. This bending of the light ray as it passes from one medium to another is known as the refraction of light. The amount of bending depends on several factors, one of which is the type of media.

3. Can you name some everyday examples where you have witnessed the refraction of light?

4. Look closely again at the prism and the spectral components into which the white light breaks: do you notice something about how each of the

colours bends? What is the difference between the refraction of red light when compared to the refraction of blue light?

5. Can you think of another factor besides the type of medium which influences the amount of refraction?

Task 2: **Experiment 2.** Scattering of light.

When light passes through transparent material, it can get scattered by particles (atoms or molecules) in the material that are much smaller than the wavelength of the ray of light: this phenomenon is called Rayleigh scattering. It plays a big role in why the sky is blue during and red during a sunset.

The effects of Rayleigh scattering in the Earth's atmosphere can be demonstrated using a flashlight, a large transparent container of water (~10 l), and a ¼ cup of whole milk. By adding a bit of the milk to the water, you can create an environment similar to that in the atmosphere (the milk represents the molecules while the water represents the atmosphere).

After adding some of the milk to the water and stirring, hold the flashlight to the side of the container so that its beam shines through the water. What happens to the colour of the beam? Now explore the effects on the colour of the beam when you change different factors in the experiment (more/less milk in the water, a longer trajectory of your beam through the mixture, etc.).

Compare your experiment to when the sunlight travels through the atmosphere:

1. Can you create an experiment that results in the light beam being bluish (i.e. a blue sky)? Write down the conditions of the experiment.
2. Can you create an experiment that results the light beam being red or yellow (i.e. a sunset)? Write down the conditions of the experiment.
3. Can you now explain why the sky is blue?
4. Can you now explain why the sky turns red during a sunset/sunrise?

Explain

WHAT'S CAUSING IT?

Task: Go back to your sketch of what happens during a lunar eclipse and combine it with the knowledge you acquired while doing the experiments to answer the next questions:

1. During a lunar eclipse, the Earth will block all sunlight from directly reaching the Moon: what effect will the Earth's atmosphere have on the sunlight?
2. Which colour has the best ability to travel through the atmosphere?
3. Look at the sketch you made of the lunar eclipse: can you, with all the knowledge you now have of refraction, dispersion, and scattering, explain why the Moon is red during a lunar eclipse instead of being completely dark?

Extend

WHAT'S SIMILAR?

Task: How can you compare a red sunset to a red moon during a lunar eclipse?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Answer the following multiple-choice questions to show your understanding of the physical phenomena behind the red Moon:

1. What happens to sunlight within the Earth's atmosphere?

a) It gets scattered.
b) It gets reflected.
c) It gets refracted.
d) It turns blue.

2. Why is the sky blue?

   a) Blue light is scattered the most because it has the shortest wavelength.

   b) Light turns blue in the atmosphere.

   c) The colour of air is blue.

   d) The colour of the ocean is reflected on the sky.

3. Why is the horizon red during sunset?

   a) After all the other colours experience extreme scattering, red is all that?s left.

   b) The Sun is a Red Giant star.

   c) The Sun cools off and becomes red.

   d) Red gets scattered the most because it has the longest wavelength.

4. Why does the Moon still receive some light when the Earth gets in front of the Sun?

   a) Atmospheric diffraction causes sunrays to bend around the Earth towards the Moon.

   b) With a lack of sunlight, stars illuminate the Moon.

   c) Earth's gravity causes sunrays to bend around the Earth towards the Moon.

   d) Atmospheric refraction causes sunrays to bend around the Earth towards the Moon.

5. Why does an eclipsed moon have the same colour as the horizon at sunset?

   a) Only red light can travel through the Earth's atmosphere without being scattered in all directions.

   b) The Moon cools off and becomes the same colour as the Sun.

   c) The Moon is illuminated by starlight, like when it gets dark on Earth.

   d) In the absence of sunlight, Mars is the primary light source.

Solid or liquid?

What's the mystery?

Some materials do not act 'normally' when you exert a force on them. They become either more liquid or more solid. Bouncing putty is a special type of clay with which it is fun to play. It bounces when you let it fall and it can be torn, stretched, and mashed back together.

DOMAIN(S)

Physics, chemistry.

SUBDOMAIN KEYWORDS

Chemistry, states of matter, features of matter.

AGE GROUP

12 to **14** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
About **30 min.**

Approximate time in classroom:
Two individual **50 min**. lessons.

SAFETY/SUPERVISION

There are no specific safety restrictions/regulations for these experiments other than the standard restrictions for every chemistry/physics lesson that involves experimentation.

Attention: students may not be allowed to use boric acid in every country!

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Bouncing putty
- Modelling clay
- Chopping board (plastic)
- Hammer
- Food colouring
- Liquid glue
- Liquid starch
- Potato starch
- 3 ml Pasteur pipette
- Heating coil with agitator
- Scale
- Magnifier
- Applicator
- Glass bar
- Measuring cylinder
- Wash bottle with distilled water
- Boric acid
- Polyvinyl alcohol
- Plastic wrap

LEARNING OBJECTIVES

Students will learn about gravity, force, and the difference between liquid and solid states of matter.

The students will be able to explain ideas about viscosity, dilatancy, thixotropy, and rheopexy; however, teachers have to consider the complexity of the wording and whether or not students can manage the technical terms.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Some materials don't act "normally" when you exert force on them. They become either more liquid or more solid. This phenomenon can occur with starch-water mixtures, ketchup, sand, and bouncing putty.

Let the students see the putty bounce. Tell a fascinating story close to the context of your class about the clay; at the right moment, let the putty bounce.

Explore

COLLECT DATA FROM EXPERIMENTS

First, the students experiment with the putty and discover its unique characteristics. They then should try to make their own bouncing putty. For this, they should be given different instructions (recipes) and outcomes. Now they can compare and modify their recipes systematically. Therefore, the students have several different materials with which to experiment (best provided on a material table).

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Thixotropy is a property exhibited by some fluids which have a gel-like consistency when they are stationary but become fluent when they are subjected to shear stress. One of the classic examples is quicksand. Other examples are toothpaste, ketchup, and wet coffee grounds.

Bouncing putty is made of chain-like polydimethylsiloxane molecules (PDMS), in which every fifth silicon atom in a hundred is replaced by a boron atom. The boron atoms have a positive charge and the oxygen atoms a negative one. Between them is a temporary electrostatic attraction: this is weak and can be broken and rebuilt in another position.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

The students can use their knowledge about dilatancy and thixotropy to experiment with other materials which do not react "normally". They can explore the characteristics of starch-water or sand-air systems and find out how they react when they exert different pressures.

Students are able to compare different systems (bouncing putty, starch-water, sand-air) and determine similarities and differences. The students get to know systems that have the characteristics of both liquids and solids.

Older students can figure out how to produce silicone polymers and learn about polymerisation reactions.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The students present their results and how they planned and executed their experiments. They compare and evaluate different recipes and strategies.

They relate their results on a macro level to their knowledge about particle models.

They can also relate the course of their work to parts of the enquiry cycle and show different ways to go through the enquiry process.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The teacher can act out Lisa's story. The teacher takes out the bouncing putty after the part of the story where Lisa's brother tickles her: the teacher let the putty fall and it bounces. The teacher acts surprised and asks: "Since when can putty bounce?" The teacher throws it harder and it bounces higher. The teacher tells the students that everyone at the party also wanted a ball like this but they could not go to the shop because it was closed. Do the students want some too? "So, let's try to make our own putty" says the teacher to end his/her story.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

At first, the students are conducting a structured enquiry (level 1) as they are starting with a recipe. They then have to explore the properties and write their observations down in the proper order.

Afterwards, the students have to vary the recipe systematically with a hypothesis in mind. They have to write down a hypothesis about the change of the properties of their new putty. They are thus conducting a guided enquiry (level 2).

The skills the students develop are: planning and conducting experiments, forming evidence-based explanations, making decisions, modifying experiments based on results, and presenting results.

Resources

In the following links, you can find explanations of the terminology used in this mystery in German:
www.chemie.de/lexikon/Nichtnewtonsches_Fluid.html

www.chemie.de/lexikon/Dilatanz.html

www.seilnacht.com/nano/nano_ela.html

Here, you see some more ideas about how to engage the students:
www.experimentis.de/wissenschaft/unterhaltsam-lustig/oobleck-nichtnewtonsche-fluide-newtonsche-flussigkeit/

www.prosieben.at/tv/galileo/videos/4267-extrem-sand-clip

More experiments with WACKER-SILICONES.
CD and print version are available here:
www.chemiedidaktik.uni-wuppertal.de/disido_cy/de/media/print/WSL-Schulversuche_A4_D.pdf

Solid or liquid?

STUDENT WORKSHEET

Listen to the following story and watch carefully. Lisa is collecting superballs. For her twelfth birthday, her brother wanted to get something special for her. However, as Lisa opens the packet, she is disappointed: it contains some green putty. She plays a bit with the putty and forms a ball; when her brother tickles her, the putty-ball falls out of her hand. The putty bounces! The best thing is, the harder you throw it, the higher it bounces. Her friends are excited and also want bouncing putty. Unfortunately all the shops are closed, but her father has an idea: "We can try to make some bouncing putty on our own."

Engage

WHAT'S INTERESTING?

Task: Bouncing putty is a great gift that is extremely versatile. Take the bouncing putty and let it bounce. What happens when a ball of bouncing putty lies motionless on the table for some time? What happens when you beat it with a hammer?

Try out other ideas. What can you do with it? Under which circumstances does the bouncing putty act differently to normal modelling clay?

Write down your ideas, hypotheses, and questions. Note your first assumptions and the questions that have arisen so far!

Explore

WHAT'S HAPPENING?

Task: Create your own bouncing putty. Try out different recipes and test the properties of your putty. Try to optimise the recipe.

The following materials are available for you to use: liquid glue, liquid starch, potato starch, boric acid, polyvinyl alcohol, food colouring.

Recipe 1 **Materials and equipment:**

- 6g liquid glue (we recommend "UHU Bastelkleber")
- 11g water
- 14.3g potato starch
- Food colouring
- Scales
- Heating plate
- Beaker
- Spoon or glass bar

Procedure:

1. Switch on the heating plate at 100°C.
2. Measure the water and the starch into a beaker.
3. Stir the mixture well.
4. Place the beaker on the heating plate and allow it to stand for ten minutes: what happens to the starch? Stir it once every minute.
5. Take the beaker off the heating plate and add a few drops of food colouring.
6. Measure 6g of the liquid glue and stir it well until the putty comes off the bottom of the beaker.
7. Cover your hand with starch (half a spoonful). Now take the putty into your hands and knead it thoroughly. If it still is too sticky, add a little bit of starch.
8. Wash your beaker straight away!
9. Store your putty in a closable can or in cling film in the fridge.

Recipe 2 **Materials and equipment:**

- 11g liquid glue (UHU Bastelkleber)
- 5.5g liquid starch
- 17.5g potato starch
- Food colouring
- Scales
- Beaker or cup
- Spoon or glass bar

Procedure:

1. Measure the liquid glue into the beaker or cup.
2. Add liquid starch and a few drops of food colouring. Stir well.
3. Now add the potato starch and stir until the putty comes off the bottom of the beaker (or cup).
4. Cover your hand with starch (half a spoonful). Now take the putty into your hands and knead it thoroughly. If it still is too sticky, add a little bit of starch.
5. Wash your beaker straight away!
6. Store your putty in a closable can or in cling film in the fridge.

Recipe 3 **Materials and equipment:**

- 10 % aqueous polyvinyl alcohol solution
- 2 % borax solution
- Food colouring
- Graduated cylinder
- Beaker
- Pipettes
- Spoon or glass bar

Procedure:

1. Measure 20 ml of the polyvinyl alcohol solution.
2. Add a few drops of food colouring.
3. Stir it well.
4. Now add 7 ml of the Borax solution.
5. Mix it thoroughly.
6. Now take the mix out of the beaker and knead it with your hands.

Task: Explore the properties of the putty and compare them with the properties of the original bouncing putty. Which properties are similar and which are different?

Explain

WHAT'S CAUSING IT?

Task: What is the secret behind the bouncing putty?

You can use the additional information or research from textbooks.

Extend

WHAT'S SIMILAR?

Task 1: Optimise! Consider how the recipe can be optimised. For example, change the amount or the ratio of the ingredients.

What do you have to consider when modifying the putty to be able to say what exactly has improved?

Task 2: What other materials have the properties you just found? Try them out.

Evaluate

WHAT'S MY UNDERSTANDING?

Task 1: Introduce to the audience on the basis of your protocol exactly how you made your bouncing putty.

Explain and demonstrate the properties of your product.

Compare the properties (bounce, flow, crack, etc.) and present them clearly in a table or graphic, marking them "weak" to "strong".

Identify together the best recipe and the reasons for the chosen criteria.

Task 2: How did you plan and execute your experiments? Refer to the enquiry cycle. Compare your methods with those used by the other groups.

The Book of Science Mysteries

The chi wheel

What's the mystery?

Can people really move objects through the power of their mind? In this lesson, students witness the amazing chi wheel, which claims to work by focusing chi energy. Students test hypotheses to obtain scientific explanations about how it really works.

DOMAIN(S)

Physics.

SUBDOMAIN KEYWORDS

Hypothesis, particles, density, particle model.

AGE GROUP

11 to **14** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
15 min.

Approximate time in classroom:
50 min. lesson.

SAFETY/SUPERVISION

Students need to be careful when using hot water. Be aware that spillages may occur and that the floor may become slippery, causing a hazard.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

For teacher demonstrations:

- A piece of paper around the size of a post-it stamp
- An eraser
- Needle, or pin to make a chi wheel. For instructions, search for 'psi wheel' on the website 'Wikihow'
- Water balloon filled with cold water (keep this in the fridge before using)
- Bowl
- Cold water from the tap
- Warm water.

Each small group of students will need:

- Large beaker of cold water
- 4 polystyrene cups
- Hot water
- Food colouring
- Disposable pipette

LEARNING OBJECTIVES

Students will describe how the spacing of particles changes as a fluid is heated and use this to explain why hot fluids rise.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Tell the class you can move things with the power of mind. Show them the chi wheel and explain that it works by sending out chi energy from your hands (see the resources section below for a video).

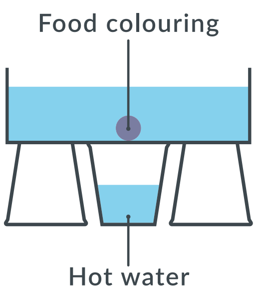
Invite a student to try the wheel. They will find that it does not move immediately. Stop the student before it moves. Secretly (so the rest of the class can see what is happening but not the volunteer) warm your hands in hot water then try. Show that you can get it to work.

Ask the class for their ideas on how it works. They should be able to suggest that warmth from the hands it making the wheel turn.

Explore

COLLECT DATA FROM EXPERIMENTS

Explore 1: experiment to test the hypothesis that hot fluids move. Students are guided on how to use the Hypothesiser Lifeline. They carry out an experiment to show that hot fluids rise.



Explore 2: why do hot fluids rise? Explain the effect of heat on particle spacing, and thus density, and how this can explain why a warm fluid rises. Then students are challenged to test the hypothesis in a further experiment. Fill a water balloon with cold water and float it in a bowl of cold water. Ask students to use particle diagrams to write a new testable hypothesis.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

Students link their answers to the previous questions and provide a complete explanation for the original mystery of the chi wheel. More able students can explain how the temperature of the object, its position and the distance it is from the wheel affects the speed of the chi wheel.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Demonstrate with a homemade hot air balloon (search on 'Wikihow') or use a video to show what happens when a hot air balloon is filled.

Discuss with students about how filling the balloon with hot air makes it rise.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

The students are challenged to apply their new ideas about particles in order to explain why a hot air balloon rises when inflated.

Student responses can be used to assess their understanding of the learning objective.

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

The engage part of the lesson is the place for showmanship. Present the chi wheel as a mysterious phenomenon. When the student volunteer is trying out the chi wheel, ask them to send chi energy from their hands to move the wheel. When you perform the trick, pretend that you are using chi energy. During this part of the lesson, do not be scientific!

We also suggest not revealing the learning objective until after the engage stage is complete so as to maintain the mystery.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Demonstrated enquiry (level 0): this takes place during explore 1. The teacher reveals to the class a basic explanation of what makes the wheel spin (the warm fluid rises). They use the hypothesiser lifeline to develop the hypothesis with students.

The students are shown the experimental set up for explore 1. They make an experimental prediction supported by the hypothesiser lifeline and then try the experiment. They will see that the food colouring rises in the colder liquid and can use the lifeline to conclude that their hypothesis was correct.

Structured enquiry (level 1): this takes place during explore 2. The teacher adds a scientific explanation to the hypothesis in terms of the effect of heat on particle spacing, and thus density, and how this can explain why a warm fluid rises. The students are then challenged to test the hypothesis in a further experiment. A water balloon is filled with cold water and floated in a bowl of cold water. The students are then asked to design a test based on the hypothesis of the effect that the heat will have on particle spacing and density. They use particle diagrams to help them predict what will happen. The only sensible suggestion which would show anything different is to put a balloon filled with cold water into a bowl of warm water (which will sink). The teacher then carries this out and the students make conclusions about their hypothesis.

Solving the mystery: students are led towards the explanation by using ideas about the particle model and how warmth from your hands causes the air around the chi wheel to become less dense and rise.

Resources

Instructions on how to make a chi wheel.
TEMI Youtube Channel:
www.goo.gl/tUDaq5

Chi wheel:
playlist> psi wheel revelead

Hot air balloon being filled:
playlist> hot air ballon launch

The chi wheel

STUDENT WORKSHEET

Some claim that the mysterious chi wheel proves that people can move objects with only the power of their minds.

Can you use science to explain how it really works?

Engage

WHAT'S INTERESTING?

Task: What did you observe? How did your teacher get the chi wheel to move

Explore

WHAT'S HAPPENING?

Task 1: One hypothesis is that warm gases and liquids rise. Set up the experiment. Use the hypothesis to make a prediction: what will happen when you put the hot water under the food colouring?

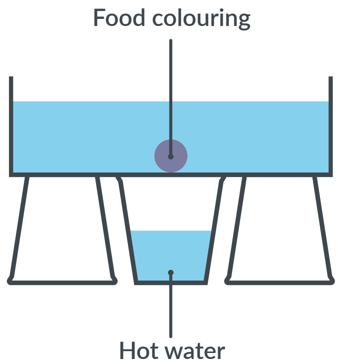
Task 2: Carry out the experiment.

Task 3: Describe what happened. What does this tell you about the hypothesis?

Task 4: What happens when particles are heated? Use this to explain your hypothesis that hot fluids rise.

Task 5: Watch your teacher carry out another experiment using a balloon. Use the lifeline to design a test to back up the hypothesis and write a prediction. Use particle diagrams to help you.

Task 6: Your teacher will carry out your test. Are your ideas correct?



Explain

WHAT'S CAUSING IT?

Task: Use what you have learnt about particles to explain how the chi wheel works.

Extend

WHAT'S SIMILAR?

Task: Watch a hot air balloon being filled with warm air. What happens?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Apply what you have learnt to explain how a hot air balloon works.

The curved light

What's the mystery?

Light rays propagate rectilinearly, as can be seen with micro-particles of powder, talcum powder, or smoke in a medium with a laser beam.
Why is the laser light in the Plexiglas pan filled with water curved?

DOMAIN(S)

Physics.

SUBDOMAIN KEYWORDS

Refraction of light.

AGE GROUP

12 to **18** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
Two hours.

Approximate time in classroom:
Three or **four** individual **50 min.** lessons**.**

SAFETY/SUPERVISION

Laser pointers have to be handled with care and never directed at people's eyes.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- Laser pointers
- Talcum powder
- Plexiglas semicylinder
- Glycerol
- Water
- Sugar syrup
- Milk
- Mineral oil
- Alcohol
- Water tanks.

To prepare the mystery, put about 8 cm of glycerol (better) or sugar syrup at the bottom of the Plexiglas pan and then add water without stirring. After about one hour of rest (it can work better after some hours or even after days), a density gradient of glycerol will be present in the pan. Throw the light of a green laser beam longitudinally through the pan near the interface between the glycerol and the water; adjusting the direction of the beam, you will see it curved towards the bottom. To better visualise the trajectory of the light, add a touch of skimmed milk to the two liquids.

LEARNING OBJECTIVES

- Qualitative behaviour of light when the medium in which it propagates changes its refraction index.
- Quantitative evaluation of the behaviour of light in refraction by means of Snell's law.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Carefully point a laser beam in different directions and through different media all around the class (be careful of reflections: lasers are dangerous, so do not point them at people's eyes). Use some talcum powder to visualise the straight beam in the air. When you direct the beam through water, transparent oils, glass prisms, etc., you will see a rectilinear propagation of the beam.

Now continue your observations by directing the laser pointer into what looks like a simple Plexiglas pan of water; in reality, this will contain also some glycerol. Watch the beam as it mysteriously curves. Why is this?

Explore

COLLECT DATA FROM EXPERIMENTS

Students may build their own experiments to investigate the trajectory of the light by using laser beams and different transparent materials such as glass, Plexiglas, water, transparent oils, and others. Once they have understood something about light's behaviour when it passes through the surface of separation between two different media (the teacher will then introduce the word refraction), they will be ready to investigate diffraction in cases where the refraction index changes continuously. It is then possible to create refraction index gradients by adding water to glycerol.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

When a light beam goes through the medium in which it propagates, its direction changes. If the optical density of the medium contains a gradient, the direction of the beam changes continuously and the trajectory appears curved. The optical density may be varied by putting sugar syrup or glycerol at the bottom of a Plexiglas pan and then adding water without stirring. After some time (the longer the duration, the better the effect) a density gradient of glycerol will be present in the pan.

A second step in the explanation can be the description of Snell's law of refraction in mathematical terms.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Refraction of light may explain many optical effects, like, for example, what happens to a straight object that appears bent on the surface of the water when it is submerged. Lenses are another immediate extension, as are cosmological gravitational lenses: these provide a very intriguing (and complex) topic that can be introduced by means of an analogy with refraction. This could interest students who are older than 14.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Students should now be able to predict, at least qualitatively, the trajectory of light in simple experimental situations.

Teachers may prepare some particular spatial variations in different media, such as prisms or liquids with different optical indexes; when doing this, the teacher can ask students to predict the trajectory of light.

If students' knowledge is such that they have already understood the topic quantitatively, then it will be possible to ask students to make quantitative predictions.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Showmanship in the presentation of the mystery is mainly focused on how the behaviour of light in the classroom is demonstrated. Darkness is fundamental. The laser lights (typically red and green) will also have to be projected normally after talcum powder is dispersed in the room. Students will therefore recognise the straight propagation of the laser beam and will be surprised at seeing the laser beam curve in the liquid contained in the pan. Wordy descriptions are not needed because the light beams speak for themselves dramatically.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: if light goes straight wherever we visualise it in the room, why does it curve in this pan?

Demonstrated enquiry (level 0).
Teacher-as-model: you show the students how to carry out an enquiry process by explaining your hypothesis and tests by 'talking aloud', which students then copy. The students record your thinking onto their hypothesiser lifeline worksheet. The teacher will start with the rectilinear propagation of light, observing that if the medium (he/she can try water, mineral oil, glycerol, alcohol, glass, Plexiglas, etc.) in which the light propagates is uniform, the light doesn't change its direction. Subsequently, the teacher will show what happens on the surface of separation between the two different media. From this last observation, the teacher will describe qualitatively what makes the trajectory of light curve.

Structured enquiry (level 1).
'We do it'. Students then use their hypothesiser lifeline to record their own alternative ideas about the direction of the propagation of the light. The teacher may prepare the experiments and students can record their thinking and their hypothesis.

Solving the mystery: students are led towards the explanation by using ideas about refraction and, when possible, Snell's law of refraction.

Resources

A very clear tutorial about the refraction of light can be found on the TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > refraction of light

In order to face the intriguing gravitational lensing, you can use the following videso on the TEMI Youtube Channel:
www.goo.gl/tUDaq5
playlist > gravitational lensing
playlist > what is gravitational lensing
playlist > refraction of light

The curved light

STUDENT WORKSHEET

You have seen a red laser beam and a green laser beam that crossed the dark classroom without bending. It really seems that the light rays propagate rectilinearly.

However, how can the laser light propagating in the Plexiglas pan appear curved when the beam passes through the liquid in the pan? What is happening inside the pan?

Engage

WHAT'S INTERESTING?

Task 1: Carefully point a laser beam in different directions and through different media. Use some talcum powder to visualise the beam, but don't point it in anyone's eyes. Be careful of reflections too.

Task 2: Now make the laser light propagate inside the Plexiglas pan so that the trajectory can be seen in the larger surface of the pan. What happens to the trajectory of the laser beam?

Explore

WHAT'S HAPPENING?

Task 1: Build your own experiments in order to investigate the trajectory of the laser light as it goes through different media: glass, water, Plexiglas, transparent oils, glycerol, alcohol, etc.

Task 2: Create other experiments using two non-miscible media with different refraction indexes (ask your teacher for help with the selection of media with different refraction indexes) in the same pan: how does the beam behave?

Explain

WHAT'S CAUSING IT?

Task 1: What happens to the direction of the propagation of the light when it doesn't change the medium in which it propagates?

Task 2: Is there a property that you can reasonably imagine in a transparent medium that has something to do with the behaviour of a light beam that enters that medium from the air of the lab?

Task 3: Using a goniometer and the plexiglas semicylinder, you can try a quantitative characterisation of the phenomenon you have just found.

Task 4: Create a qualitative model that could explain the curve trajectory of a laser beam using your previous knowledge about the the concept of refraction.

Extend

WHAT'S SIMILAR?

Task 1: Recognise refraction in the optical effects all around yourself. For example, pay attention to what happens to straight objects that are partially submerged in water: they appear broken on the water's surface. You can do this yourself with a simple set-up.

Task 2: Lenses and mirages also work by means of refraction.

Task 3: Gravitational lenses are the last related topic. They are very intriguing and complex, and can be approached with an analogy to glass lenses.

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Test your ability to predict the trajectory of a laser beam that propagates in different experimental situations. Conduct different experiments using prisms, liquids, or other transparent objects and guess the trajectory of the beam.

The card colours command

What's the mystery?

A shuffled pack of cards seems to be under the control of your voice commands, as you can predict the number of red and black cards in two piles that are lying face down on the desk.

DOMAIN(S)

Mathematics.

SUBDOMAIN KEYWORDS

Algebra, equation, mathematical model, mathematical proof.

AGE GROUP

15 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
One hour for practising the trick and understanding the algebra used in the solution.

Approximate time in classroom:
One hour in classroom with the students as they explore the trick and mathematics..

SAFETY/SUPERVISION

None, just ensure that a full deck of 52 cards is used.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

- A standard pack of 52 playing cards with no jokers.
- Pencil and paper to record information in experiments.

LEARNING OBJECTIVES

Student will learn about the basics of algebra, such as variables, constraints, and equation substitution.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Say you will show your ability to control playing cards with the power of your voice!

Shuffle the cards and turn over the top card; if it's red, put it face up and deal another card face down while declaring that it is red. This pile is your red pile. If the top card is black, put it on the other side and deal another card face down while saying that it is black: this is your black pile. Go through the entire pack this way.

The piles on the table will look like this:

- Red cards face up.
- Face-down card pile called the red pile.

- Black cards face up.
- Face-down card pile called the black pile.

Though the deck is shuffled, your "word commands" ensure that there are the same number of red cards in the red pile as there are black cards in the black pile.

Explore

COLLECT DATA FROM EXPERIMENTS

Collect all the cards and shuffle again: then do a series of experiments exploring this phenomenon. You can have the students do these experiments in groups.

1. What happens if you say different words when dealing the facedown cards? Or don't say anything? Does it make any difference?
2. What happens if you just deal the cards randomly into four piles? Is there any pattern to the places where you find the red and black cards?
3. What happens if you shuffle the undealt cards in your hands as you go along?
4. What happens when you try different types of shuffles or get a friend to shuffle at the beginning?

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

The trick is based on algebra and is a nice example of how to introduce the idea that algebra allows us to model a system; in this case, the system is how the cards end up in the piles.

Call the number of cards in the red pile R0: be sure to just use a letter instead of the actual number, as the actual number will be different each time you do the trick. Call the number of cards in the face up black pile B0, again just using a letter to let you be general about the number. What other piles on the table have R0 and B0 number of cards in them? As the deck is shuffled, you can't know the exact numbers of red and black cards in the piles, but again you can use letters: in this way, you can write down some facts about the numbers. In the red pile, let's say there are R1 red cards and B1 black cards: what do R1 and B1 need to add up to? In the black pile, let's say there are R2 red and B2 black: what do R2 and B2 need to sum to?

The number and the colours of cards on the table are represented algebraically as follows.

- **R0** (Red cards face up)
- **R1+B1** (Face-down card pile called the red pile)

- **B0** (Black cards face up)
- **R2+B2** (Face-down card pile called the black pile)

We have the equation **R0+R1+R2=26**, meaning that the total number of red cards on the table is 26 (half a pack of 52 cards). What can you say about **B0+B1+B2**: what's it equal to?

If R1+B1= R0, the number of face-down red and black cards in the red pile is equal to the number of face-up red cards in the pile above it: is there a way you can use this fact and the fact that R2+B2=B0 to show that R1 will always equal B2 for the trick if you follow the instructions?

Answer:
R0 + R1 + R2 = 26 (call this equation (1)).
B0 + B1 + B2 = 26 (call this equation (2)).
R0 = R1 + B1 (call this equation (3)).
B0 = R2 + B2 (call this equation (4)).

So if we substitute equation (3) into equation (1) and eliminate R1, we get:
(R1 + B1) + R1 + R2 = 26 (call this equation (5)).

Similarly, if we substitute equation (4) into equation (2) and eliminate B0, we get:
(R2 + B2) + B1 + B2 = 26 (call this equation (6)).

Combining equations (5) and (6), as both add up to 26, we get:
(R1 + B1) + R1 + R2 = (R2 + B2) + B1 + B2

Collecting similar terms gives us:
2R1+B1+R2=2B2+R2+B1

We can subtract R2 and B1 from each side of the equation. This leaves:
2xR1 = 2xB2

We can divide both sides by two, giving us R1=B2. This means that for every full pack of cards dealt with the correct procedure, the number of red cards in the face-down red pile always equals the number of black cards in the face-down black pile, which is exactly what your prediction is.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

In this trick, you have created what scientists call a **mathematical model.** By using letters to represent the number of cards, we can understand what's happening and be sure of the situations where the trick will always work. We can also use it to predict how things will work if we make changes. For example, you may be able to come up with different presentations or perhaps different predictions of the outcome if you change the number of cards in the pack.

The letters that represent numbers that can change are called variables because they can vary; here, B1 and R2 are variables. Constraints are things that fix the way the model acts; for example, here we have constraints that R0+R1+R2=B0+B1+B2=26 (we are using a full deck) and R0=R1+B1 (we deal a card face down under every face-up red card). **Variables and constraints** combine to give us powerful mathematical models in science and engineering; for example, they are very useful for checking if a bridge will carry traffic or making software do what you want.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Set a few questions on the basics of algebraic manipulation.

E.g. If A=B+C and D=B, then what can we say that's always true? Answer: A=C+D

Set the students a challenge. If you wanted to perform the trick so that there are equal numbers of red and black cards in the face-down piles, then the result would be exactly one more red card than black cards. How could you do this?

Answer: secretly remove two black cards before you start the trick.

THE 5E MODEL

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

This is a nice direct magic trick and you should present it as such; so long as the instructions are followed, it will work every time. This means you can try swapping the same number of cards from one face-down pile to the other, saying "you got those ones wrong". Develop your own style of presentation and enjoy the looks of astonishment.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Setting up the mystery: tell the class that they can determine how the cards fall by words alone.

Demonstrated enquiry (level 0): teacher-as-model. You show how to carry out an enquiry process, which the students then copy; for example, does the shuffling of the cards as you deal the piles make a difference? Explain your hypothesis and tests by "talking aloud". Students record their thinking onto their hypothesiser lifeline worksheet.

Structured enquiry (level 1): "we do it". Students use their hypothesiser lifeline sheet to record their own alternative ideas about why colours separate and to record their tests and conclusions regarding these other possible explanations.

Solving the mystery: students are led towards the explanation by using ideas about the use of algebra and abstraction to show why the trick works.

Resources

Videos showing this trick, as well as others, being performed and explained using a different "body language reading" presentation can be found at:
www.mathematicalmagic.com

The application of magic in teaching computer science algorithms and free books to download can be found at:
www.cs4fn.org/magic

The card colours command

STUDENT WORKSHEET

Can your thoughts and words control the colours of the unseen cards you deal when playing with a normal pack of cards?

Engage
WHAT'S INTERESTING?

Task: With a pack of cards in your hands, follow the teacher's instructions to create two random piles of face-down cards. Although you shuffled and dealt randomly, your teacher can magically predict the numbers of cards of each colour.

Explore
WHAT'S HAPPENING?

Task: Follow the teacher's instructions to perform the trick. The piles on the table will look like this:

» Red cards face up.
» Face-down card pile called the red pile.

» Black cards face up.
» Face-down card pile called the black pile.

What happens if you say different words when dealing the face-down cards? Or don't say anything? Does it make any difference?

What happens if you just deal the cards randomly into four piles? Is there any pattern to the places where you find the red and black cards?

What happens if you shuffle the undealt cards in your hands as you go along?

What happens when you try different types of shuffles or get a friend to shuffle at the beginning?

What happens if you just use ten red cards and ten black cards and follow the instructions?

Explain
WHAT'S CAUSING IT?

Task 1: Think about all the things that can change in this trick, like the number of cards in each pile. These are called variables and can be represented by letters rather than numbers.

The things that are always the same in this trick are called constraints. What can you say about the total number of red cards in all the piles? What about the number of cards in the face-down pile compared to the face-up pile above it?

Do the trick a few times and write down the number of red and black cards in each pile. Share this data with other students. Is there a pattern in the numbers?

Task 2: Make a list of variables and constraints.

Variables are things that can change while constraints are things that are always fixed.

What about the number of face-up red cards dealt: does this vary each time the trick is performed?

What about the total number of black cards in all the piles: can that ever be different?

Task 3: Write these variables and constraints using letters instead of numbers. The number and colours of cards on the table can be represented as follows:

- **R0** (Red cards face up)
- **R1+B1** (Face-down card pile called the red pile)

- **B0** (Black cards face up)
- **R2+B2** (Face-down card pile called the black pile)

Can you create a set of equations from this?

What does R0 equal in terms of the other variables?

How can you use these equations and a simple equation substitution to help show that the trick always works?

What is a substitution? If, for example, A=B+C and C=2D, then we can replace C in the first equation with its value 2D to show that A=B+2D.

Extend

WHAT'S SIMILAR?

Task: You have created a mathematical model for the card trick and used mathematics to prove that it will always work: what other sorts of scientific or engineering processes would you want to be sure worked every time, even under different conditions? Aircraft landing gear? Buildings? Bridges?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: What if you wanted to perform the trick differently so that, rather than having equal numbers of red and black cards in the face-down piles, the result was that there would be exactly one more red card than black cards?

What could you do?

Would it always work?

The timely prediction

What's the mystery?

A random number is freely generated by the learners, only for the teacher to magically match it to a prediction about the current date or location.

DOMAIN(S)

Mathematics.

SUBDOMAIN KEYWORDS

Addition grids, tables, magic mathematical row column, matrix.

AGE GROUP

8 to **14** years old (with different levels of differentiation).

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation: **30 min**.

Approximate time in classroom: **40 min**.

SAFETY/SUPERVISION

No safety precautions required.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

» Paper
» Pens
» Grids of numbers prepared by teacher similar to those shown in this document
» Calculators

LEARNING OBJECTIVES

Student will practise addition and subtraction skills. They will also explore number patterns and data structures such as matrices.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

Tell the students that you made a prediction a while ago specifically for today. Hand one of them a prediction on a folded piece of paper to read later.

Proclaim you had a dream about a truly random number that was chosen and you want them to create a truly random number now. You don't want their number to be influenced by anything in their minds already, so say that you brought some random number grids to help with the choices. They can pick any grid they like (see the grids at the bottom of this document).

Now they must choose four numbers on their chosen grid. To ensure there is no relationship between the numbers and that they are all random, they must not pick two numbers that share a row or column. So there should be four numbers: one from each row and one from each column. To make this clearer, whenever they pick a number, you can circle it and cross out the rest of the row and column.

Now the final stage in creating their random number is to add the four chosen numbers; once they find the total, they should look at the prediction. In this case, the total will always be 30.

Explore

COLLECT DATA FROM EXPERIMENTS

Hand the students the tables and ask them some prompting questions:

» How did you know the total was going to be 30? (It will always be 30).

» What happens to the trick if I take one of the grids we used and swap around a couple of columns? What about if I swapped a couple of rows? The trick should still work.

» Can you design another grid where the total will always be 30?

» Are there any really obvious grids you could make where the total will definitely be 30? How about if the only numbers you used were 0 and 30? What about if you only used 15 and 0?

» How can you edit these obvious grids to make them more confusing? Could you swap any numbers around or split up the values in an interesting way?

» How do the rows in the tables compare to each other? Is this the same with the columns? Each row is a consistent amount more or less than the row above or below.

» Could this idea now help you make a more complicated grid where the result will also always be 30?

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

This trick works because the grids are actually addition tables. The numbers on the top and the far left that you add to get the sum for each square are invisible. I wonder if they can fill in the invisible row and column headings for the addition table? What do they notice about the column and row headings for each square? In each case, they add up to 30. Why is this important? By picking one from each row and column and adding them together, you are essentially adding all the row and column headings once; thus, you will end up with 30.

As an example, here is the first table with the addition grid numbers included.

The numbers in blue around the outside add up to 30.

The numbers in the grid form a simple matrix: this gives you the opportunity to discus what a matrix is and how it contains rows and columns of numbers.

It may be useful to introduce the mathematics with a simpler 2x2 grid. The first grid produces the sum 2+3+1+5=11. Students may find it easier to discover the pattern in such smaller grids.
The second grid shows how the grid looks for a negative seed number: this grid produces the sum 3-2+1+5=7.

+	1	5	4	2
7	8	12	11	9
1	2	6	5	3
8	9	13	12	10
2	3	7	6	4

+	2	3
1	3	4
5	7	8

+	-2	3
1	-1	4
5	3	8

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Can you now pick a new final number and create a grid that works for it? It doesn't have to be a 4x4 grid (yes, larger square grid sizes also work).

What about if we included negative numbers (it works for those too)?

Could we do something similar with multiplication (yes, it works for multiplication too, as it's a commutative operation like addition)?

Choose one of your grids. If you swap the rows around or swap the columns around or do both, you still get a working grid. However, you do not always get a working grid from this set of numbers; if you scrambled up your numbers completely, it probably wouldn't work. Can all workable grids with your chosen numbers be made just from row or column swaps? Or are there some other working grids you can make with these numbers that you can't get to with row or column swaps?

The lower grid shows how the grid looks with a negative seed number: this grid produces the sum 3-2+1+5=7.

+	-2	3
1	-1	4
5	3	8

Further ideas and information can be found at:
www.deceptionary.com/aboutmatrices.html

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

Have students present their working grids or their findings on what makes a grid workable to the rest of the class.

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

Use the date or something related to the location as a predicition number. Then write "it is today's date" on the prediciton paper.

It is also good to really emphasise the randomness of the numbers being chosen and how we are going through this process to make sure that the number is completely random and not affected by earlier thoughts. The effect works independently, so enjoy the presentation and find your own style as a magician. Practise your performance a few times before doing it in public.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Tell the class they must add up four numbers from a chosen grid: one from each row and one from each column.

Demonstrated enquiry (level 0): have different grids on the board that will not produce 30 and model how the students should select one number from each row and column.

Structured enquiry (level 1): students should have a go at adding up four numbers to get the predicted number. They should then experiment a few times to see if this always happens and write down their theories about why this works.

Solving the mystery: students are led towards the explanation by using the given questions to lead them to the invisible addition grid.

Resources

The necessary tables are at the end of this document. However, it would be a good idea to make your own with another number that is more relevant. Also see the "Magic of Computer Science Book 1":
www.cs4fn.org/magic/downloads/cs4fnmagicbook1.pdf

In the book (p. 53), the square of fortune gives a different presentation and resources on the computer science applications of the mathematical principle at the basis of this trick. For instance, they discuss its application to medical imaging.

The concept of a forcing matrix, more methods, and a spreadsheet for grid generation is given at:
www.deceptionary.com/aboutmatrices.html

The timely prediction

STUDENT WORKSHEET

You have seen that the randomly chosen number was predicted at the very beginning.
You should investigate how this can be accomplished.

Engage
WHAT'S INTERESTING?

Task: How can the teacher predict the result of your free choices?

Explore
WHAT'S HAPPENING?

Task: What do you notice about the numbers in the grid?

Write down any patterns you see in the numbers.

What happens if you redraw a grid and swap two columns of numbers: does the trick still work?

What happens if you swap rows?

Explain
WHAT'S CAUSING IT?

Task: Look at the example grid on the next column.

Imagine there are extra invisible numbers round the grid, represented here by '?'

What numbers would you need to put in each box with a '?' so that they add together to give the corresponding number in the grid?

+	?	?	?	?
?	8	12	11	9
?	2	6	5	3
?	9	13	12	10
?	3	7	6	4

For example, what two numbers add together to give 8?

It may be 7+1. Now look at the next box along, 12: what numbers would be in the '?' boxes? Remember that the '?' box for the top row must be either 7 or 1 to make the first 8.

Now consider 11: again, what two numbers add together to give 11? Remember again that one of them must come from either 7 or 1 to give the first 8 and the second 12.

Can you see a pattern developing as you work out all the missing '?' values?

Extend

WHAT'S SIMILAR?

Task: Could you now pick a new final number and create a grid that works for this? It doesn't have to be a 4x4 grid.

What about if we included negative numbers?

Could we do something similar with multiplication? If so why?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Create your own grid and make your own prediction. Present your version of the trick to the rest of the class

Tell the class about your findings on what makes a grid work.

10	5	6	9
7	2	3	6
11	6	7	10
12	7	8	11

10	3	9	2
13	6	12	5
12	5	11	4
11	4	10	3

6	10	8	7
5	9	7	6
3	7	5	4
9	13	11	10

5	7	13	6
8	10	16	9
2	4	10	3
4	6	12	5

11	8	5	9
8	5	2	6
13	10	7	11
9	6	3	7

Your numbers divided

What's the mystery?

You are able to predict numbers that exactly divide a series of random numbers chosen by students.

DOMAIN(S)

Mathematics.

SUBDOMAIN KEYWORDS

Divisors, prime numbers, prime factorisation.

AGE GROUP

15 to **16** years old.

EXPECTED TIME FOR THE MYSTERY

Approximate time for teacher preparation:
10 min

Approximate time in classroom:
One hour

SAFETY/SUPERVISION

None.

Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.

PREPARATION AND LIST OF MATERIALS

Calculators or student mobile phones if allowed in class.

LEARNING OBJECTIVES

Students will understand prime numbers and prime factors of numbers.

Guidance notes for teachers

THE 5E MODEL

Engage

CAPTURE STUDENTS' ATTENTION

You ask three students to use their calculators (or mobile phones if allowed) to enter a random number. You state you will be able to predict numbers that will exactly divide their chosen random number. Ask them to enter any three-digit number on the calculator and to keep it hidden from you.

Pretend to get premonitions from each of them, saying that with just three digits it´s too easy; to make it harder, they should each use a larger number. So they enter the same three-digit number again to give a six-digit number. For example, if they entered 345 initially, then their new number would be 345345.

You are then able to instantly tell each of them a different small number that will exactly divide their personal six-digit number: the first number is divisible by 7, the second by 11, and the third by 13. They each perform the division and show that you are right: there is no remainder.

For final part of the trick, you say you will instantly calculate a six-digit number that is exactly divisible by the three small numbers you already gave: the three numbers derived from their initial free choices. You tell them this six-digit number and again the calculator shows you have been able to correctly calculate the number in your head.

The secret of the trick is that the three small numbers you call out are always 7, 11, and 13. The rest of the trick works by itself.

Explore

COLLECT DATA FROM EXPERIMENTS

You can repeat the trick again; however, this time, get the class to write down all the numbers you use. Then get them to look for patterns in this numerical data: what can be seen?

They should notice that in the numbers used:

1. The personal three-digit numbers need to be repeated (e.g. 432432).
2. They should notice the factors are always 7, 11, and 13, even if you call them out in a different order.
3. They should notice the final six-digit number you give is a repeated three-digit number.

Explain

WHAT'S THE SCIENCE BEHIND THE MYSTERY?

The trick relies on the fact that entering any three-digit number followed by the same three digits again is exactly the same as multiplying the original three-digit number by 1001. For example, 345345 is 345 x 1001.

The small numbers you use in your predictions and 7, 11, and 13 are the prime factors of 1001. Remember that in number theory, the prime factors of a positive integer are the prime numbers that divide that integer exactly. The unique prime factorisation theorem states that every integer greater than one is either a prime number itself or is the product of prime numbers and that this product is unique.

Therefore, only 7, 11, or 13 will divide exactly into any of the students' duplicated personal numbers. The final part of the trick showing your mathematical powers simply involves you giving any six-digit number that is a repetition of any three-digit number (e.g. 765765). This will of course be divisible by 7, 11, and 13 due to the same mathematical principal.

PRIME FACTORS TREE

	1001		
	/ \		
7		143	
		/ \	
	11		13

Prime[4] = 7, Prime[5] = 11, Prime[6] = 13

Prime factors tree image from the prime factor calculator website: www.calculatorsoup.com/calculators/math/prime-factors.php

The data collected when you perform the trick again, along with hints about the relevance of primes to the trick working and leading them to the revelation that multiplication by 1001 is identical to repeating a three-digit number, will support them in discovering the principle behind the trick.

Extend

WHAT OTHER RELATED AREAS CAN BE EXPLORED?

Will the trick work with a single digit repeated three times? The answer is yes, as 333333 is 333 x 1001

Can students find the prime factors of the following numbers?
9 (answer: 3).
39 (answer: 3 and 13).

Determining the prime factors of a number is an example of a technique frequently used to ensure cryptographic security in encryption for online shopping.

Evaluate

CHECK THE LEVEL OF STUDENT SCIENTIFIC UNDERSTANDING

You can evaluate their understanding of prime numbers and prime factors by posing the following questions:

» Will the trick work for a single-digit number (e.g. initial number 3, duplicated number 33)?

» The answer is no: 33 is 3 multiplied by 11 and 11 is a prime number with no prime factors.

» Will the trick work for a two-digit duplicated number (e.g. 3434)?

» The answer is no: 3434 is 34 multiplied by 101 and 101 is a prime number with no prime factors.

You might want to have the students try and calculate the prime factors of some numbers by hand; see, www.calculatorsoup.com/calculators/math/prime-factors.php

Showmanship

TIPS ON HOW TO TEACH AND PRESENT THIS MYSTERY

This trick is easy to do and works by itself: you just need to remember the instructions and the numbers 7, 11, and 13. Chose a presentation you are happy with and practise it a few times in private before you perform. Ensure that the students know to enter the same three digits twice by giving them an example. Do try and make this digit duplication look like it is you trying to make the trick harder rather than something to make the trick work. When predicting the numbers, 7,11, and 13, look strained and get the students each to confirm that you are correct.

The final section with a six-digit number should be done slowly, again making it look like it is taking effort to calculate the final figure from the numbers you gave earlier. The more you can make it seem that you could have predicted any three numbers based on the personal numbers the students entered, the stronger the effect.

Letting students use the calculator on their own phones, if allowed, can add a personal touch and remove any suspicion about trick school calculators.

When teaching the maths, getting to the 1001 multiplication revelation may need to be signposted more for the weaker students through suitable hints.

GRR

TEACHING SKILLS USING GRADUAL RELEASE OF RESPONSIBILITY

Demonstrated enquiry (level 0): teacher-as-model. You show how to carry out an enquiry process, which students then copy. Explain your hypothesis and tests by 'talking aloud'. Students then record your thinking onto their Hypothesiser Lifeline sheet. This includes indicating the numbers you use, thus presenting the data they need to collect and analyse.

Structured enquiry (level 1): 'we do it'. Students then use their Hypothesiser Lifeline sheet to record their own alternative ideas about why the trick works and to record their tests and conclusions regarding other possible explanations by running a series of experiments themselves. Here they look at whether single and double digit numbers work and the importance of prime numbers to the solutions.

Solving the mystery: students are led towards the explanation by using ideas about prime factorisation and number patterns when multiplying by 1001.

Resources

Videos showing this trick, among others, being performed and explained to teach basic mathematics can be found at: **www.mathematicalmagic.com**

An online prime factor calculator can be found at: **www.calculatorsoup.com/calculators/math/prime-factors.php**

This also shows how to manually calculate prime factors.

Your numbers divided

STUDENT WORKSHEET

Numbers have a life of their own and contain lots of interesting properties. Here we can explore an one such property by performing a magic prediction trick with just your calculator or mobile phone.

Engage

WHAT'S INTERESTING?

Task: How can your teacher make these predictions about the numbers you all freely chose and how are they able to calculate the final six-digit number in their head so quickly?

Explore

WHAT'S HAPPENING?

Task: What do you notice about the numbers used? Write these down: these will be the data you can use to help explain the trick.

When the trick is repeated, what new clues (data) can you discover: write down your information and ideas about how the trick works.

Explain

WHAT'S CAUSING IT?

Task: What's interesting and important about the numbers 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, and 31?

What's interesting and important about the numbers 345345, 987987, 123123, and numbers like these? Is there a pattern you can see?

Starting from, say, 456, who can get to 456456 in a different way than by just repeating the initial three-digit number?

Extend

WHAT'S SIMILAR?

Task: Would the trick work if you entered three digits identical to your first number? If so, why?

Evaluate

WHAT'S MY UNDERSTANDING?

Task: Would the trick work if we start with a two-digit number? If not, why not?

The Book of Science Mysteries

The Hypothesiser Lifeline

The Hypothesiser Lifeline illustrated on the next page is an example of a cognitive scaffold that can be built into **TEMI methodology**. A cognitive scaffold summaries the processes students need to follow to carry out an enquiry skill. These have been used successfully in other subjects where the **TEMI GRR** model has been used. It is repeated student´s use of these strategies, which helps students internalise the thinking and move towards perform the enquiry skill on their own.

HYPOTHESIS 1

Things I can do to test this:

Results of test:

Reason for rejection/acceptance of hypothesis :

HYPOTHESIS 2

Things I can do to test this:

Results of test:

Reason for rejection/acceptance of hypothesis :

Hypothesiser Lifeline

OBSERVE
What did you see happen?

EXPLAIN
What is your hypothesis (idea) for why it happened? What science do you know to back up your idea?

TEST
If your idea is correct, and you do an experiment to test it (you decide what the experiment is). Then, what do you predict will happen?

CONCLUDE
What did you find out in your test? Can you conclude that your hypothesis is correct or wrong?

KEY WORDS
Hypothesis: Explanation of what you are going to test
Observation: What you can see (hear or smell)
Prediction: What you expect to happen
Conclusion: What you have found out

Construct Explanations Lifeline

1. WRITE DOWN YOUR OBSERVATIONS

Remember to use scientific words

2. RECALL ANY RELEVANT SCIENCE IDEAS

Search your memory for science ideas that could explain your observations. List a few below.

CHOOSE ONE IDEA

3. CONNECT THE IDEA TO YOUR OBSERVATIONS

Draw a picture wich connects the science idea to your observation.

DOES THIS IDEA HELP TO EXPLAIN YOUR OBSERVATIONS?

NO
CHOOSE ANOTHER IDEA

YES
WRITE THE EXPLANATION

4. WRITE A CLEAR AND ORGANISED EXPLANATION

I can explain (write down the part of the observation that the science idea can explain) using the science idea of... (idea)

Your explanation should include:

- ☐ What the science idea tells us in general
- ☐ What the science idea tells us was happening this case
- ☐ Which part of the observation the science idea can explain

KEY WORDS

Observation: What you can see (hear or smell)

The Book of Science Mysteries

Characterisation sheet

This sheet will help you to assess activities and characterise them with respect to the four TEMI innovations.

How to fill in the form:

① Start by discussing the **mystery**. By **mystery**, we don't mean the whole activity, but rather the scientific mystery at the base of the activity. Is the mystery productive? Is the phenomenon mysterious? Is the mystery relevant for IBSE?

② Continue to the **5E model**, which helps assess the **IBSE** aspect of the activity. How does each of the 5Es get expressed in the activity? (Note: not all activities need to include each of the 5Es).

③ **Showmanship** can be evaluated using the ICE model. The ICE model evaluates three dimensions of the showmanship experience:

Interactivity: to what extent and in what ways are students (inter)active in the experience?

Classroom: what is the physical classroom arrangement? How are students seated? What physical props are needed?

Exposition: How does the teacher expose or present the activity? Is there use of a story? What voice does the teacher use to talk to the students?

The purpose of showmanship is to create a holistic experience. Thus, the three dimensions must merge to create an overall experience. Is this the case in the activity? If not, how can this be fixed?

④ **GRR**

Which skills can be developed in the activity? Mark which dimensions are currently supported in the activity and which dimensions you think the activity can support.

⑤ **Spider chart**

The spider chart can give an overall view of the expression of each innovation in the activity.

For each innovation, mark how you think the innovation is expressed:

1. there is little expression of the innovation in the activity.
2. there is some expression of the innovation in the activity.
3. there is substantial expression of the innovation in the activity.
4. the innovation is a major part of the activity.

Do so for each of the four innovations. Connect the lines and you will get a web. The web shows the strengths and weaknesses of the activity.

⑥ Under the table, you will also find a space for giving a star and for making a wish (see below). Next to the star, you may comment something in the activity that is particularly noteworthy. Next to the wish, you may suggest an improvement to the activity.

Give a Star
Make a Wish

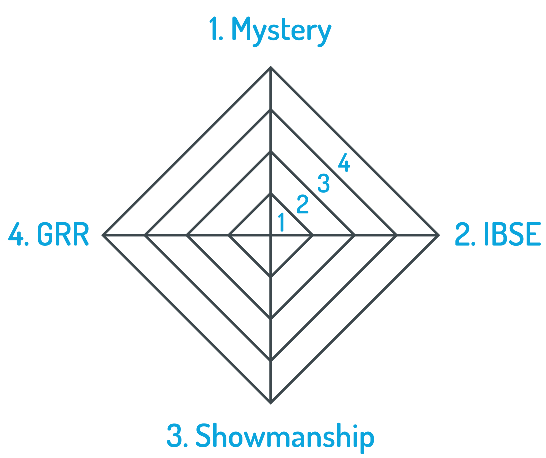
Characterisation Sheet

Name of the Activity:

Group members:

1. THE MYSTERY

Is the mystery productive? Is the phenomenon mysterious? Is the mystery relevant for IBSE?	



2. IBSE: THE 5E MODEL

Engage	
Explore	
Explain	
Expand	
Evaluate	

3. SHOWMANSHIP - THE ICE MODEL

Interactivity (Student)	
Classroom arrangement (Physical)	
Exposition (Teacher)	
Do the ingredients merge well to form a good ICE experience?	

4. GRR

Which of the following skill/s are currently developed in the activity (circle in the list below)? Which other skill/s could be developed in this activity (mark by an asterix)?

Explore	Explore
Explain	Explain
Expand	Expand
Evaluate	Evaluate
Other:	

Give a Star	
Make a wish	

Final thoughts

In this book, you will have discovered new and interesting ways to effectively engage your students to undertake science-based enquiry learning. We hope you have found at least one classroom activity you can try and that the teaching support materials, worksheets, and hints and tips we provided will make it a truly effective lesson. As your skills grow, we hope you will also enjoy creating your own ideas and resources based on the TEMI methodology and so have an effective new form of science teaching to call upon.

Thank you for using this book, and good luck with exploring the mysteries.

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