Gravity and the bouncing bomb: teacher and facilitator guidance notes

Introduction

A range of suggested activities and a narrative is suggested in this guidance. The activities link Isaac Newton's laws on gravity and Barnes Wallis' bouncing bomb. Curriculum links are provided alongside each activity.

Accompanying support materials are also included. The video file *bouncing_bomb.wmv* should be saved into the same folder as the presentation to ensure that the video runs correctly in the presentation. The presentation slides are advanced using a mouse button click or forward arrows on the keyboard. You may see a security warning on your computer when you ope the presentation. This is due to it containing and anmation and video clip.

Full risk assessments should be carried out before performing any suggested activities.

Newton and Gravity

Isaac Newton stated his law of universal gravity in his work, Principia Mathematica, published in 1687. It states:

Every particle in the universe exerts a force on every other particle along the line joining their centres. The magnitude of the force is directly proportional to the product of the masses of the two particles, and inversely proportional to the square of the distances between them.

The most evident experience of this force is how objects have weight and fall towards the Earth. However, for a full understanding, it should be noted that all objects attract each other. The size of the force depends on the mass of the objects and their distance apart. For example:

- The Earth's gravitational pull on the Moon keeps it in orbit around the Earth.
- The Moon's gravitational pull on water in the Earth's oceans and seas causes the tides.
- The gravitational pull of the Sun keeps the planets of the solar system in orbit around the Sun.

Newton observed gravity pulling an apple towards the Earth as it fell from a tree. At the same time, the Earth was also attracted to the apple. The falling apple can be noticed. The gravitational pull of the apple on the Earth is so small that it has no discernible effect.

Mass and weight

It is important to make the distinction between mass and weight, as they are terms that are often misused interchangeably.

The **mass** of an object is the amount of material it is made of. The mass remains the same anywhere in the universe. Mass is measured in **kilograms (kg)**. Unfortunately, this unit is also often used when talking about the weight of common items.

The **weight** of an object is the force applied on it by gravity. The unit of force is a **newton (N)**. The weight of an object will vary depending on the gravity acting on it. An object on the Moon, will weigh less than the same object back on Earth.

On the Earth, a mass of 1kg has a weight of 9.8N. For convenience, 1kg is often referred to as having a weight of 10N. It is rare to ask for 10N of apples.

Investigation: How quickly do objects of different weights fall?

This activity can be carried out as a demonstration or as a participant investigation.

The idea is to see if heavier objects fall more quickly than lighter ones. It is somewhat counter-intuitive, but the answer is that all objects fall with the same acceleration. This was shown by an experiment in which Galileo dropped cannon balls of different weights off the Leaning Tower of Pisa. He observed that they hit the floor at the same time.

This observation challenged the previously accepted dogma that heavier objects will fall more quickly than lighter ones. This was the view of the ancient Greek philosopher Aristotle and had been held as true for hundreds of years.

Note that a falling object accelerates as it falls. That is, gravity is making the object move quicker and quicker. Therefore the use of the term speed should be used in the knowledge that a falling object's speed is constantly changing. The level of depth of explanation should be tailored to suit the audience.

Curriculum links

Key stage 2

Scientific enquiry: Investigative Skills

- planning
- obtaining and presenting evidence
- considering evidence and evaluating

Physical processes: Forces and Motion

- objects are pulled downwards because of the gravitational attraction between them and the Earth

Key stage 3

Key Concepts: Scientific thinking

- using scientific ideas and models to explain phenomena

Key Processes: Critical understanding of evidence

- obtain, record and analyse data
- use findings to provide evidence for scientific explanations
- evaluate scientific evidence and working methods

Range and content: Energy, electricity and forces

- forces are interactions between objects and can affect their shape and motion

Materials

A range of objects can be dropped. The main cause for confusing results is the effects of air resistance, and so very small or light objects should be avoided. For example, beach balls tend to float rather than fall.

Balls are readily obtainable and do not cause damage if dropped sensibly. Balls of the same size but with different weights can be achieved by using tennis balls, some with sand added through a small hole before being resealed. Alternatively, foam tennis balls are also available for comparison.

Using balls of different sizes can allow a discussion on controlling variables.

An introduction to the investigation is given in the accompanying presentation and an activity sheet is also included.

Activity

Participants drop different balls simultaneously from the same height. They judge if they hit the floor at different times or not.

This is always difficult to judge and can lead to a discussion on the accuracy and reliability of observations. How could they be made better? Some possible discussions include:

- Using a greater height gives more time to see the fall (but do not allow participants to stand on tables of chairs).
- Using a mechanical device to ensure that the drops are simultaneous.
- Taking a video recording of the drops and then analysing using slow motion.

Summary

It may be difficult to convince participants that the objects hit the ground at the same time.

Describe the experiment by Galileo and finally show the video of Apollo 15 astronaut doing the same experiment on the Moon. As there is no air resistance, the video shows a hammer and a feather falling at the same speed in the Moon's gravitational field.

The video can be downloaded from the UK ESERO resources collection on the STEM eLibrary at: http://stem.org.uk/rx3ce

Further video clips, illustrating the movement of people and objects in weightless conditions in space, can be found at: http://stem.org.uk/rx6br

How quickly do objects of different weights fall?

The ancient Greek philosopher, Aristotle, said that heavy weights will fall faster than lighter ones.
After all, a feather falls slower than a stone.

Galileo, an Italian scientist born in 1564, thought that objects of different weights fall at the same speed.

He dropped cannon balls off the Leaning Tower of Pisa to see if he was correct.

Who do you think was right? Aristotle or Galileo?

Do an experiment to find out.

Demonstration: The monkey and the hunter

This is quite a difficult demonstration or investigation. Full instructions, a video and guidance can be found in the National STEM Centre eLibrary at: http://stem.org.uk/rx436

The scene is that a hunter sits in a tree some distance from a monkey in another tree. Both the monkey and the hunter are at the same height.

The hunter aims horizontally at the monkey and fires their gun. At this instance, the monkey releases their grip on the tree and drops vertically downwards.

Will the bullet pass harmlessly over the monkey's head or will it be hit?

The answer is that, as both the bullet and monkey fall vertically at the same speed, the monkey will be hit by the bullet. Remind participants about their earlier investigation into falling objects. The horizontal motion of the bullet does not influence the effects of gravity acting on the bullet.

After viewing the video, it may be worthwhile seeing if participants can recreate the demonstration using a peashooter and cardboard monkey. Peashooters are available from toy shops and an activity sheet is supplied.

Take care with the peashooters to avoid any participants being hit in the eye. Safety glasses should be worn. Peashooter mouthpieces should be cleaned thoroughly if they are to be shared and after use. Warn users not to inhale the projectile. Choose a peashooter with a grill to prevent this happening.

Curriculum links

Key stage 2

Physical processes: Forces and Motion

- objects are pulled downwards because of the gravitational attraction between them and the Earth

Key stage 3

Key Concepts: Scientific thinking

- using scientific ideas and models to explain phenomena

Range and content: Energy, electricity and forces

- forces are interactions between objects and can affect their shape and motion

The Monkey and the Hunter

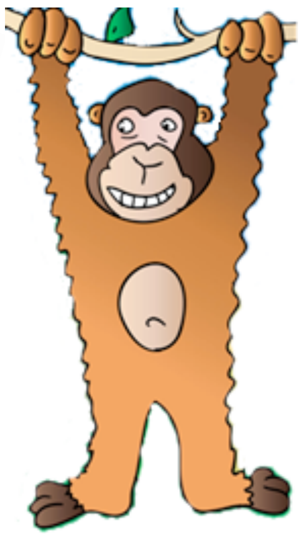
The scene is set............

A hunter sits in a tree some distance from a monkey in another tree. Both the monkey and the hunter are at the same height.

The hunter looks at the monkey. The monkey has a plan and stares back at the hunter.

The hunter aims their gun horizontally at the monkey and fires. At this instance, the monkey releases their grip on the tree and drops vertically downwards.

Will the bullet pass harmlessly over the monkey’s head?



Or will the monkey be hit?

Investigation: Helium balloons and lift

This activity sees participants measuring how much lift can be generated by a 'party-style' helium-filled balloon. This can then be used to calculate how many balloons it would take to lift an apple against the force of gravity.

Early flight used 'lighter than air' balloons. Strictly speaking, it is the density of the gas inside the balloon that matters. Less dense than air and the gas will generate uplift. This can be thought of as similar to objects floating in water. Materials less dense than water will float. Those that are more dense will sink.

Hot air balloons fly (or 'float') because the air inside the balloon is heated by the burner and is less dense than the colder air outside. An airship contains helium gas which is less dense than air and so it rises. Early airships contained hydrogen gas but this is too flammable and no longer used.

When considering balloons, also think about the material the balloon is made of and any structures it carries. This will add weight and so inhibit the balloon from rising. The volume of the balloon needs to be sufficient to generate enough lift to overcome the total weight of the balloon and its load.

Curriculum links

Key stage 2

Scientific enquiry: Investigative Skills

- planning
- obtaining and presenting evidence
- considering evidence and evaluating

Physical processes: Forces and Motion

- objects are pulled downwards because of the gravitational attraction between them and the Earth
- how to measure forces and identify the direction in which they act

Key stage 3

Key Concepts: Scientific thinking

- using scientific ideas and models to explain phenomena

Key Processes: Practical and enquiry skills

- plan and carry out practical and investigative activities, both individually and in groups.

Key Processes: Critical understanding of evidence

- obtain, record and analyse data
- use findings to provide evidence for scientific explanations
- evaluate scientific evidence and working methods

Range and content: Energy, electricity and forces

- forces are interactions between objects and can affect their shape and motion

Materials

Helium-filled balloons that float (typically available from card or gift shops). Tie three long cotton threads to each balloon – long enough so that balloons can be retrieved if they float to the ceiling. One per group of children.

Use fine cotton thread so that the weight of the threads can be ignored.

Small, lightweight plastic or paper disposable cups.

Sticky tape and dispenser.

Sand and plastic spoons (only a small amount will be needed per group). Any safe material can be added to the plastic cup, e.g. sugar or salt

Digital scales to weigh the sand and cup (electronic kitchen scales weighing in 0.1g intervals would be ideal).

Bathroom scales.

Several apples of different sizes.

Activity sheet included in the support materials.

Activity

Have the participants work in small groups. Each group has one helium balloon, cup and sticky tape.

Participants first hold the helium balloon to experience the pull of the balloon's lift. They then attach the paper cup and add sand so that the balloon just floats level. The combined weight of the sand and the cup equals the amount of lift produced by the balloon. Too little sand and the balloon will rise as the upwards lift is greater than the downward weight. Too much sand and the balloon will sink as the weight exceeds the lift.

Participants can draw a diagram and indicate the forces acting on the balloon: lift upwards and weight downwards.

Use the scales to measure the weight of the sand and cup. Measure the weight of one of the apples. Use these results to calculate the number of balloons needed to lift one of the apples.

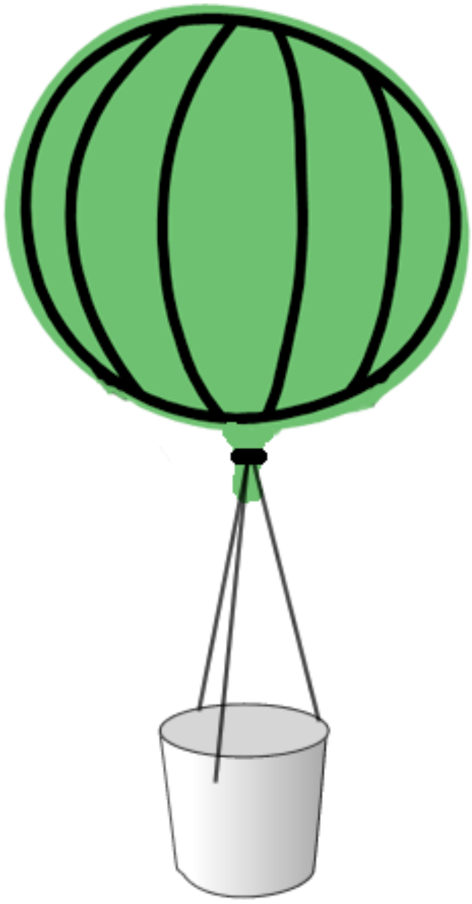
If available, participants can measure their own weight and calculate how many balloons it would take to lift them.

Summary

As the apples are of different sizes, groups are likely to have different answers. This can lead to a discussion about creating standards to define measurements of weight and mass. The National Physics Laboratory, in Middlesex, has the UK's National Standard Kilogram. This is a copy of the international prototype and is the standard for all mass measurements in the UK. Their web site is at: http://www.npl.co.uk

How much can a helium balloon lift?

You are going to see how much a helium-filled balloon can lift.



1. Hold onto the strings.
   Feel the balloon pulling up.
2. Get a small cup.
3. Use sticky tape to attach the strings from your balloon to the cup.
   You need to be able to put sand inside the cup.
4. Check to see that it still floats upwards.
5. Use a spoon to put a small amount of sand inside the cup.
   Check to see if the balloon still floats.
6. Put just enough sand into the cup so that the balloon just floats level.
7. Use the scales to find the weight of the cup and sand.

   This is the amount that the balloon can lift.

Calculate how many balloons it would take to lift an apple.

Hint: you may need to weigh the apple first.

How many balloons would it take to lift you?

Barnes Wallis, the Bouncing Bomb and the Dambusters raid

During World War II, it was decided to attack reservoirs in Germany's industrial Ruhr valley. The plan was to destroy the Möhne , Sorpe and Eder dams in an operation codenamed 'Chastise'.

Barnes Wallis developed the concept of a 'bouncing bomb.' In order to deliver a bomb to the face of a dam, he suggested producing a bomb that would skip along the surface of the water in the reservoir. In order to achieve success, each bomb would need to be dropped from a height of just 60feet (18m) above the water, 425yards (388m) from the dam whilst the aeroplane was flying at 220mph (354kph).

Operation Chastise took place on the night of the 16 May 1943. The Möhne Dam was destroyed, flooding the valley below. The Eder Dam was also breached. Poor visibility meant that the raid on the Sorpe Dam did very little damage.

133 airmen took part in the raid. 53 were killed and three were captured after bailing out. Flooding caused the deaths of over 1,300 people in the valleys below the Möhne and Eder dams.

More details on the Dambusters raid are available from the National Archive web site at: http://www.nationalarchives.gov.uk/dambusters

Demonstration: Bouncing a projectile off water

It is possible to demonstrate bouncing a small projectile off the surface of water.

A peashooter is a good way of launching a small, round projectile and these are readily available from toy shops. Peashooter mouthpieces should be cleaned thoroughly if they are to be shared, and after use.

A suitable surface of water can be obtained using a shallow tray or dish, such as an oven tray. Use the peashooter to fire a the projectile at the surface. Fire the projectile from close range to the water and at a very shallow, almost flat, angle. The projectile will skip off the water and continue across the room (do not fire in the direction of participants).

Show that steeper angles will result in the projectile burying itself into the water. This illustrates the importance of delivering the bouncing bombs at a specific angle to the water's surface.

The demonstration can be made into a fun activity by challenging participants to hit a target placed on the other side of the water.

Take care with the peashooters to avoid any participants being hit in the eye. Safety glasses should be worn. Warn users not to inhale the projectile. Choose a peashooter with a grill to prevent this happening.

Investigation: The relationship between drop height and bounce height

Included in the presentation is a short video showing bouncing bomb tests in 1943 and a simple animation, that illustrates the need to drop a bomb from a specific height.

With limited resources, it is not possible to replicate an investigation that looks at objects skipping over a surface of water. So, in this investigation, participants look at the relationship between the height that a ball bounces compared to the height it is dropped. This allows a 'model' to be developed that begins to look at how a bouncing bomb may behave. There must be sufficient bounces for a bomb to reach the dam wall, but at the same time, the final bounce must not be so high that it would pass over the dam.

The activity is relatively simple to undertake but raises many good questions about experimental design and the accuracy of observations:

- It is difficult to judge the height of a bounce accurately. Video recording (camera phones or camcorders) can help to capture the data for more accurate review.
- Parallax error can be significant when viewing a scale attached to a wall behind the bouncing ball.
- Participants must drop the ball and not 'push' it as if bouncing the ball.

Careful measurements can usually gain good results. Data can be entered into a spread sheet to enable its rapid processing and the production of a straight line graph.

The investigation can be extended to compare balls made from different materials or being dropped onto different surfaces, for example tiles and carpet.

Curriculum links

Key stage 2

Scientific enquiry: Investigative Skills

- planning
- obtaining and presenting evidence
- considering evidence and evaluating

Physical processes: Forces and Motion

- objects are pulled downwards because of the gravitational attraction between them and the Earth

Key stage 3

Key Processes: Practical and enquiry skills

- plan and carry out practical and investigative activities, both individually and in groups.

Key Processes: Critical understanding of evidence

- obtain, record and analyse data

- use findings to provide evidence for scientific explanations
- evaluate scientific evidence and working methods

Range and content: Energy, electricity and forces

- forces are interactions between objects and can affect their shape and motion

Materials

Tennis or table tennis balls (or similar).

Tape measure or metre rules (can be attached to a wall behind the drop).

Activity sheet and sample spread sheet provided. The spread sheet can have fresh data entered and this automatically updates the graph. Alternatively, it can be used as an example and a new spread sheet developed.

Activity

Participants will need to work in groups of three or four. Do not allow participants to climb on chairs or tables to get to greater drop heights.

Participants drop a ball from a known height and record how high it bounces. This is repeated to gain a meaningful average for a range of drop heights.

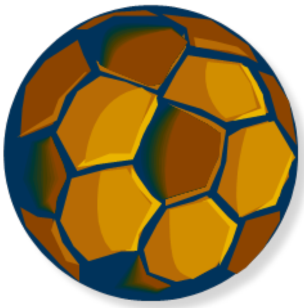
Summary

Participants often get a good, linear relationship, between drop height and bounce height. The spread sheet provided is programmed to give a straight line of best fit, passing through the origin (no drop height gives no bounce).

Stress to participants that this type of modelling can give information that leads to a mathematical understanding of the process. The spread sheet is set up to display the equation for the straight line produced by their results.

Mathematical equations produced from such data can be used to apply a model in new areas. It would not have been possible for Barnes Wallis to carry out unlimited random tests using bombers and manufactured bombs. He first needed to calculate the combination of drop speed, height, bomb weight and construction that was most likely to be successful. Prototypes could then be tested and refined.

What is the relationship between the height a ball is dropped from and the height it bounces to?



What do you think will happen?

How can you test you idea?

What will you change (variable) and
what will you keep the same (control)?

What measurements will you need to take?

How can you make sure your observations are reliable?

How will you process and present your results?