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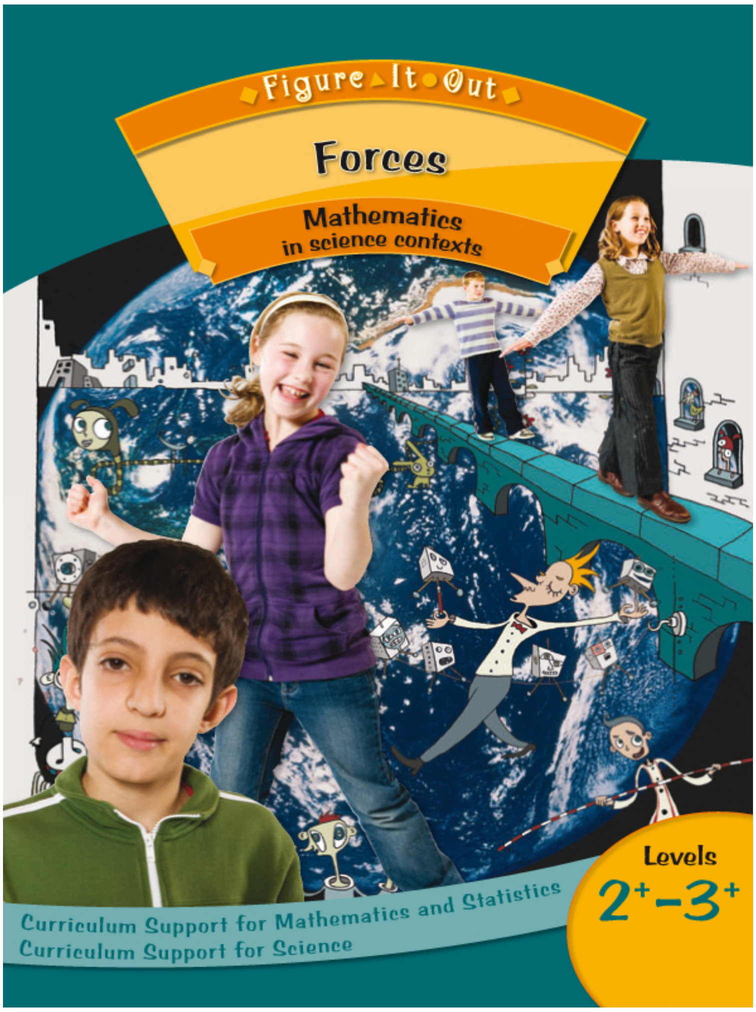
The New Zealand Curriculum

Teacher Support Material
(including Answers)



MINISTRY OF EDUCATION
Te Tāhuhu o te Mātauranga

Contents

Introduction

The books in the Figure It Out series are issued by the Ministry of Education to provide support material for use in New Zealand classrooms. The achievement objectives for mathematics and statistics and for science and the key competencies referred to in this *Teacher Support Material (including Answers)* are from *The New Zealand Curriculum.*

Student books

The activities in the Figure It Out student books are written for New Zealand students and are set in meaningful contexts, including real-life and imaginary scenarios. The contexts in the level 2^+–3^+ *Forces* book reflect the ethnic and cultural diversity and the life experiences that are meaningful to students in years 4–6. However, you should use your judgment as to whether to use the student book with older or younger students who are also working at these levels.

Figure It Out activities can be used as the focus for teacher-led lessons, for students working in groups, or for independent activities. You can also use the activities to fill knowledge gaps (hot spots), to reinforce knowledge that has just been taught, to help students develop mental strategies, or to provide further opportunities for students moving between strategy stages of the Number Framework.

Teacher Support Material (including Answers)

In this new format, the answers are placed with the support material that they relate to. The answers are directed to the students and include full solutions and explanatory notes. Students can use these for self-marking, or you can use them for teacher-directed marking. The teacher support material for each activity, game, or investigation includes comments on mathematics and science ideas, processes, and principles, as well as suggestions on teaching approaches. The *Teacher Support Material (including Answers)* for *Forces* can also be downloaded from the nzmaths website at www.nzmaths.co.nz/node/1994

Using Figure It Out in the classroom

Where applicable, each page of the student book starts with a list of equipment that the students will need in order to do the activities. Encourage the students to be responsible for collecting the equipment they need and returning it at the end of the session.

Many of the activities suggest different ways of recording the solution to the problem. Encourage your students to write down as much as they can about how they did investigations or found solutions, including drawing diagrams. Discussion and oral presentation of answers is encouraged in many activities, and you may wish to ask the students to do this even where the suggested instruction is to write down the answer.

Students will have various ways of solving problems or presenting the process they have used and the solution. You should acknowledge successful ways of solving questions or problems, and where more effective or efficient processes can be used, encourage the students to consider other ways of solving a particular problem.

Figure It Out

Forces

Mathematics in science contexts

Teacher Support Material (including Answers)

Overview of Forces, Levels 2^+–3^+

Title	Focus	Page in students' book	Page in support material
Introducing Forces	Finding out about forces	1	8
Rocket Balloon	Relating pressure, mass, angle, and speed	2–3	11
Flying High	Measuring the effect of different variables	4–6	15
High or Low?	Investigating relationships	7–9	21
See-saw Antics	Gathering and reporting data and investigating patterns and relationships	10–11	25
Skateboarding Theory	Exploring relationships	12–13	29
High Wire	Exploring angles, position, weight, and length and their relationships	14–15	32
Swing Time	Exploring weight and period and identifying trends	16–18	37
Zoom, Zoom!	Measuring variables accurately and exploring data	19–21	41
Gearing Up	Observing and interpreting changes in ratio	22–24	45

Introduction to Science

> Science is a way of investigating, understanding, and explaining our natural, physical world and the wider universe.
>
> *The New Zealand Curriculum,* page 28

Inquiry in science is called investigating. Science investigations can take many forms, including classifying and identifying, pattern seeking, exploring, investigating models, fair testing, making things, and developing systems. Investigating in science may involve more than one type of investigation. Scientists choose the appropriate type of investigation to answer their question(s). Each investigation can share elements with other investigations. Science investigations also provide students with rich contexts for mathematical opportunities as they decide what and how to measure, what units to use, and how to record findings as they identify trends and patterns and describe relationships. See www.tki.org.nz/r/science/science_is/dssa/focus_07_approach_e.php for examples of different types of science investigations and activities that illustrate them.

Much of the science in the Figure It Out *Forces* students' book involves the investigation of relationships. This is often done through a fair-testing investigation, where one variable is changed and its effect on another is measured while others are kept constant. The results of such investigations are best shown in a graph: the independent variable (what you change) is plotted along the horizontal (x) axis; the dependent variable (what you measure) is plotted on the vertical (y) axis. This means the effect of the changes is shown by the shape of the graph; the slope shows the nature of the relationship. Creating and interpreting graphs – a major emphasis in the mathematics and statistics learning area of *The New Zealand Curriculum* – is therefore directly relevant to interpreting the results of science investigations.

Several of the investigations in the book introduce concepts that will be explored in levels 2–6 and beyond in the science learning area, for example, relationships between force and motion. The teacher support material for the students' book includes conceptual background material and suggestions for wider and deeper exploration. However, you are the best judge of how far to take a particular idea with your students. For example, while the density investigation on pages **7–9** of the students' book is suitable for students working at level 3, it could also be extended to those at level 4 through a discussion about Archimedes' principle and buoyancy. Similarly, the activity on page **1** introduces students to the difference between mass and weight – this can be seen as one activity or used as the starting point for an investigation into more complex ideas, such as relative density.

Notes:

- Terms in the glossary are bolded the first time that they appear in the notes for each activity title.
- Internet links: on the downloadable version of this support material (www.nzmaths.co.nz/node/1994), all the Internet links can be activated by clicking on a hyperlink.

Investigating in Science

EXPLORING A SITUATION

A problem, question, situation, phenomenon, artefact, model, event, story

I wonder why ...?
I wonder how ...?

OBSERVE

What is happening?

What changes happen?

What materials are involved?

What are the main parts?

What are the key aspects?

What do these parts do?

ASKING QUESTIONS

Why? How? What? When? Where?

PLANNING AN INVESTIGATION

What will we observe/measure?
What do we want to find out?
How can we find out? What can we do to find out? Are there things we need to change or keep the same?

MAKING PREDICTIONS

What do we think will happen and why?

GATHERING DATA

Find out, measure, compare, verify, test, clarify, identify

PROCESSING AND INTERPRETING

Creating personal explanations supported by evidence

What is the cause and effect of change?

What patterns keep occurring?

What parts are interacting with other parts?

What are the outcomes of these interactions?

EVALUATION

What do the results mean?

Does our investigation answer our question?

Do our results support or challenge our predictions?

Is there another explanation for what we found out?

What do other people think about our investigation?

What have other people found?

APPLICATION AND SHARING OF NEW THINKING

How could we use our idea or explanation?

Does it explain other things?

What next, where to now?

FURTHER INVESTIGATION

Do we have another question to investigate?

Is there another idea or explanation that needs testing?

Glossary of related terms

Arc: a portion of the circumference of a circle

Buoyancy: the upward force of flotation in a fluid. Buoyancy is proportional to the amount of fluid displaced and the density of the fluid. For example, a steel ship floats in water as long as it encloses a large enough volume of air that the average density of the ship is lower than the average density of water.

Density: a measure of mass per unit volume. For example, lead has a higher density than feathers; 1 cubic metre of lead has a much greater mass than 1 cubic metre of feathers, but they have the same volume.

Effort: the input force you apply to one end of a lever

Energy: a measure of how much work can be performed (the ability to do work). If an engine lifts 1 kilogram 1 metre against gravity, it does 10 joules of work.

Experimental error: differences between measured values and the actual values, due to human mistakes, inaccurate measurement tools, inconsistent experimental set-up, or random variation

Fair testing or fair trial: where one independent variable is changed and its effect on another is measured while other variables are kept constant. For example, in an experiment measuring how far a car will roll from ramps of different heights, starting the same car from the same point on the ramp should give a fair trial, while using different cars or starting from different points would not be a fair trial.

Force: something that causes a change in the motion of an object (acceleration). For example, you exert a force on a ball when you kick it, and the speed and/or direction of the ball changes.

> **Force of gravity**: all masses attract each other. This attraction is called gravity. For example, the mass of the Sun pulls the mass of Earth into an orbit around it. Bigger, closer masses attract more strongly. The pull of the mass of Earth on your mass is the force of gravity. (Your mass also pulls on the mass of Earth, but because your mass is very small compared to the mass of Earth, the force of your mass acting on Earth is negligible.)

> **Turning force (moment)**: Turning force is the turning effect of a force about a pivot. It is defined as the force multiplied by the perpendicular distance from the pivot. For example, if you tap one end of a pencil at a right angle to its length, it will spin around.

Frequency: the number of a particular event or occurrence within a certain period of time. For example, if a rope swing goes back and forth 10 times in a minute, the frequency is 10/min.

Friction: a force caused by the rubbing of two surfaces against each other. Friction resists (acts against the direction of) motion and is proportional to the force that presses the two surfaces together. For example, the more weight on top of a piece of paper, the harder it is to slide it along the top of a desk.

Fulcrum: the pivot point of a lever

Function: a mathematical relationship between two or more variables, where the same inputs always produce the same output. For example, 3 pumps of air in a balloon should cause the balloon to travel about the same distance every time.

Gravity: the force caused by the attraction of mass

> **Centre of gravity**: the point in an object through which gravity effectively acts. On Earth, the centre of gravity is the centre of mass (the point in an object around which all mass is concentrated and in equilibrium, for example, the point where you can balance an object).

Hypothesis: a proposed relationship, prediction, or estimate (not a guess) of the future results of an experiment. A hypothesis should be testable, for example, a student might propose the hypothesis that a heavier car will roll down the same ramp faster than a lighter car.

Inverse: something that will return a quantity to the original state, or "undo" an operation. For example, the inverse of multiplying by 2 is dividing by 2.

Load: the force against which the lever is working. For example, on a crowbar, the load is the force exerted by the nail you are trying to pry out.

Mass: the amount of "stuff" (matter) in an object, measured in grams

Momentum: a measure of the mass of an object multiplied by its velocity. Momentum is conserved (not lost). For example, if a 10 kg ball travelling down a track at 2 metres per second (m/s) rolls into a 5 kg ball at rest, momentum will transfer from the 10 kg ball into the 5 kg ball, and the 5 kg ball will roll away at 4 m/s.

Multivariate: a data set that includes more than one variable. For example, an experiment observing the effect of both ramp height and ramp material on the rolling distance of a car analyses two independent variables (height and material).

Newtons: see **Work**

Outliers: measurements that are much higher or lower than most other measurements. For example, in the set {1, 20, 21, 19, 22, 18, 25, 300, 19, 20, 23}, 1 and 300 are outliers.

Glossary of related terms

Period: the time taken to return to the starting point. For example, if it takes a clock pendulum half a second to tick, the period is 0.5 seconds. Period is the inverse (reciprocal) of frequency.

Prediction: scientifically, a testable statement about the future. For example, you might predict that the average height of the girls will be greater than the average height of the boys in a certain class.

Radius: the distance from the centre of a circle to its edge

Ratio: one quantity in relation to another. For example, if there are 12 boys and 14 girls in a classroom, the ratio of boys to girls is 12:14 or 6:7.

Symmetrical: an object is symmetrical when one side is the mirror reflection of the other.

Variable: something that can change or be changed, for example, height of a ramp or time of day

> **Controlled variable**: a variable in an experiment that is kept the same in order to prevent it from affecting other variables of interest. For example, in an experiment measuring how far a car will roll from ramps of different heights, the choice of car should be controlled by always using the same car.
>
> **Dependent variable**: a variable in an experiment that changes because of a change made to an independent variable. For example, in an experiment measuring how far a car will roll from ramps of different heights, the dependent variable is the distance rolled.
>
> **Independent variable**: a variable in an experiment that is changed in order to measure the effect on other variables. For example, in an experiment measuring how far a car will roll from ramps of different heights, the independent variable is the ramp height.

Weight: the force of gravity acting on a mass. For example, a mass of 1 kg will have a weight of about 1 kg on Earth and a weight of about 0.17 kg on the Moon, but its mass will be 1 kg in both places.

Work: a change in energy, measured as force x distance. In science, force (for example, weight) is measured in newtons, but in mathematics, weight is more commonly described in terms of kilograms.

Teacher Support Material (including Answers)

Page 1: Introducing Forces

Mathematics and Statistics Achievement Objective

- Measurement: Create and use appropriate units and devices to measure ... weight (mass) ... (Geometry and Measurement, level 2)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Communicating in science: Begin to use a range of scientific symbols, conventions, and vocabulary (Nature of Science, level 3)
- Physical inquiry and physics concepts: ... identify and describe the effect of forces (contact and non-contact) on the motion of objects ... (Physical World, level 3)

Mathematics and statistics context

Students will:

- work with constants and variables (mass is constant regardless of gravity; weight is variable)
- investigate proportional relationships – when one quantity varies directly according to another (for example, the force of gravity and mass).

Students should discover that:

- force is proportional to mass.

Science context

Students will:

- define and investigate force, mass, and weight
- discuss forces and investigate how force relates to gravity
- apply their definitions to different contexts (for example, the force of gravity, forcing an oar against water, or the force of a spring).

Students should discover that:

- forces are invisible but can be measured indirectly by their effect on physical objects
- mass and weight are different
- weight is a function of gravity acting on mass.

Related information

Mass and weight: www.windows.ucar.edu/tour/link=/glossary/mass.html and http://hyperphysics.phy-astr.gsu.edu/hbase/mass.html

Information about planets, and depictions of work, force, and power: http://dev.cpo.com/home/Portals/2/Media/post_sale_content/PSN/Ancillaries/U3/U3_Teaching_Illustrations/PSN_U3_TI.pdf

Activity

Answers

1. **a.** When you bowl a tenpin bowling ball, you put force on the ball. The momentum of the ball (the moving object) will push against anything it hits, in this case, the pins.

   b. Examples could include: pushing a supermarket trolley, pulling your shoelaces tight, pushing someone over, or pulling a weed out of the garden. (Examples of inanimate objects could include a boat pulling a water skier or a machine pulling a post out of the ground.)

   c. When you pull on a rope (for example, in a tug of war or using a rope to help you climb a mountain), you exert a force on your end of the rope.

   The more force you use to push or pull, the more energy you use and the greater the effect on the object being pushed or pulled. For example, when you gently push off the ground on a skateboard, you roll a little bit, but if you push off hard, you go much faster.

2. a. The mass of objects causes the force of gravity. Massive objects, like Earth and the Moon, exert a lot of force. Earth pulls on the Moon, and the Moon pulls on Earth. The Moon's force causes the tides. The Earth's force keeps the Moon locked in orbit around Earth instead of flying into outer space.

   b. An apple falls to the ground because of the force of gravity exerted by the mass of the Earth. It's the same force that keeps the Moon from flying away.

   c. The Earth's gravity is a pull that draws everything to the ground. The force of gravity is what gives us weight. Weight is a force; mass isn't.

3. In everyday life, most people use "weight" to mean weight or mass. But in science, weight and mass have different meanings. Mass refers to the amount of material in an object (for example, the amount of matter in a 10 tonne truck) and weight refers to how that object is being pulled by gravity (for example, if a 10 tonne truck fell over a cliff, its weight would be the force with which gravity pulled it down).

   The Earth has more gravity than the Moon so a 10 tonne truck on the Moon has less weight than the same truck on Earth, even though the mass is the same. A 10 tonne truck floating in outer space would have no weight at all! Another way to think about the difference between mass and weight is to imagine going for a swim. Buoyancy counteracts the effects of gravity and you float, even though you still have the same mass as you have on land.

Notes

Preparation and points to note

Make sure the students have access to computers and/or reference books to find good data. You may wish to suggest some age-appropriate websites (see the section on related information). Set ground rules about pushing and pulling, for example, *We're studying forces, not experiencing them!* Note that action and reaction will be explored in the next activity, Rocket Balloon.

This activity is ideal for focusing on the key competency *thinking* because students will be exploring **forces*** by using their own experiences and ideas and the information that they research.

Your students will have a variety of prior knowledge, ideas, and misconceptions about **mass**, **weight**, and force. Encourage them to test and argue their ideas and find evidence or counter-arguments through their investigations. Force is a subtle idea. People had incorrect ideas about force for thousands of years before Newton – and after. Students need to be explicitly taught the norms of mathematical argumentation and that it's the ideas that are competing and being evaluated, not them.

Most students will have intuitive knowledge of forces, so questioning strategies that prompt the students to probe deeper into their own thinking will probably be more valuable than direct explanation.

Although the term weight is commonly used in general conversation to mean mass, mass and weight are not the same thing. In mathematics and science, the terms have specific and very different meanings. Weight is the **force of gravity** acting on mass. A good way to help the students understand the difference is to ask them to imagine trying to weigh a rocket ship in outer space. Even if they had a scale large enough, there would be no way to put the rocket ship on it and no force pressing it down onto the scale. It would weigh nothing, even though it clearly has a lot of mass. Body mass is another good example. On Earth, a student might have a body mass of 40 kg. On the Moon, that same student would still have the same body mass but their weight would be $\frac{1}{6}$ of their weight on Earth. (See the answers for questions **2** and **3** for more on mass and weight.)

Points of entry: Mathematics

Encourage the students to have conversations about the nature of constants and **variables**: some things don't vary with location or motion, while other things do. (The mass of an object doesn't change whether it's in a pool, on Earth, or in outer space. Weight varies in moving escalators, on swings, in water, or in outer space.)

* For bolded terms, see the glossary, pages 6–7

Prompt the students to think about relationships and proportions. Ask: *Will a tennis ball knock down as many pins as a bowling ball? Why does the bowling ball knock down the pin and not vice versa? Which has more gravity, the Earth or the Moon?* (Hint: *Where do you weigh more?)*

Note that, for this Figure It Out book, we have avoided the use of a **newton** as a unit of measure because it is not a commonly used measurement in mathematics. (For your information, mass is measured in kilograms, force in newtons. You may wonder why, if weight is a measure of force, we describe weight in terms of kilograms … in fact, we should talk about weight in newtons, but kilograms is commonly used as shorthand.)

Points of entry: Science

Mass, force, **gravity**, and weight can be difficult concepts for students to understand. Most will need multiple examples or representations of each idea to construct a robust definition. Challenge the students to test their definitions across many contexts to see if they can be applied universally (for example, ask: *How is the force of a bowling ball similar to the force of gravity? What is the force of a bowling ball?)*.

Concrete and counter-intuitive representations of mass are helpful. For example, bring in a cricket ball, a tennis ball, a bowling ball, and a beach ball and ask the students to rank them in terms of the size of the balls and which has the most mass. Have the students conduct actual or imagined experiments with the force transferred by the different balls when they hit something.

Group and regroup the students strategically so that they are exposed to a variety of examples and are asked to justify their thinking to a variety of classmates. In this way, they are using and developing the key competency *relating to others*.

Gravity is a **function** of mass and distance. A large object far away has relatively less force of gravity than a smaller, closer object. It's because the Moon is so far away that it barely affects your weight on Earth.

Some students will quickly grasp the fact that if gravity is a function of mass, their own bodies create a (small) force of gravity. Not only is Earth pulling at them, but they are also pulling at Earth. Ask *What would happen if everyone moved to New Zealand: would the Earth get pulled into a shape that isn't as round?* (If everyone on Earth did move to New Zealand, the Earth would get pulled into a shape that was only very slightly less round. Essentially, we would create a bit of a dip in the ocean on the other side of the planet and a slightly higher tide in New Zealand because water moves in response to gravity much more than rock does.)

Pages 2–3: Rocket Balloon

Mathematics and Statistics Achievement Objectives

- Measurement: Use linear scales and whole numbers of metric units for length ... weight (mass), angle ... and time (Geometry and Measurement, level 3)
- Position and orientation: Use a co-ordinate system or the language of direction and distance to specify locations and describe paths (Geometry and Measurement, level 3)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Communicating in science: Begin to use a range of scientific symbols, conventions, and vocabulary (Nature of Science, level 3)
- Physical inquiry and physics concepts: Explore, describe, and represent patterns and trends for everyday examples of physical phenomena, such as movement, forces, electricity and magnetism, light, sound, waves, and heat (Physical World, level 3)

Mathematics and statistics context

Students will:

- measure mass, angle, time, and pressure
- record data in tables
- find the function relationships between pressure, mass, distance, time, and angle for a rocket balloon.

Students should discover that:

- force is proportional to mass (you need a bigger force to push a bigger mass the same distance)
- the relative magnitude of the force of gravity depends on the angle at which it's being measured, (for example, the acceleration of gravity is constant yet exerts no force in a direction parallel to the ground)
- the balloon's jet force is a function of pressure (how much air you put in the balloon).

Science context

Students will:

- investigate Newton's second and third laws of motion (force = mass x acceleration; for every action, there is an equal and opposite reaction) using a rocket balloon
- pursue the scientific inquiry method (see page 5): make predictions about movement and use elements of fair testing to identify how force affects movement
- explore the fact that forces have direction as well as magnitude.

Students should discover that:

- we can predict changes in motion (acceleration) based on force and mass
- changes in motion are caused by the combination of all forces acting on a object
- the pressure of air maintains the shape of the balloon
- when pressure pushes air out of the balloon, there is a reaction force that pushes the balloon in the other direction
- gravity "pulls down".

Related information

Building Science Concepts: Book 42, *Marbles*; Book 30, *The Air around Us*; and Book 17, *Flight*

The New Zealand Institute of Physics: www.nzip.org.nz

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Activity One

Answers

1. a.–b. Practical activity. Results and observations will vary. (As long as the straw can move freely along the string, the balloon will shoot across the room. The air trapped inside the rocket balloon is under greater pressure than the air outside [that's why the balloon "blows up"]. When this pressurised air is allowed to escape, it rushes out of the balloon. [Newton's third law states that to every action there is an equal and opposite reaction. The balloon moves in the opposite direction to the escaping air.] The rocket balloon works the same way as you would if you were standing on a skateboard holding a heavy backpack. If you throw the backpack one way, you roll the other way. In this case, instead of a backpack, the rocket balloon "throws" air one way and jets off the other way.)

   c. The balloon always moves in the opposite direction from the jet of air.

2. The more compressed air there is in the balloon, the more force it will have and the faster it will move. If you decrease the number of pumps (lower the air pressure), the balloon has less force and will go slower.

3. Results will vary. Shape probably doesn't make much difference, although some shapes will need more air to fill up and other shapes will release the air faster (more force!). A large balloon will be affected by the air and wind more than a long skinny balloon, but in a classroom, the amount of air you put in each balloon is probably more important than air resistance.

4. a.–b. Practical activity. Predictions and results will vary. With the added mass, it will require more force to move the balloon, so you'll need to pump more air into it to move it at the same speed as before. The more mass you add, the harder it will be to get the balloon moving. If you put too much mass on the balloon, the force generated by the air escaping from the balloon won't be enough to move the combined mass of the balloon and weights.

Notes

Preparation and points to note

Make sure that there is enough uninterrupted space for the strings to stretch across the room without crossing.

Plan some initial exploration to help the students identify which direction the balloon will travel when the air is released. They will also need to practise co-ordinating their timing with the release of the balloon. For example, one student could hold the balloon closed until the person starting the stopwatch calls out "go". Using a set length of string with a designated end mark makes timing easier: one student could watch the end and shout "stop" as the balloon crosses the mark. Note: By keeping the distance constant and measuring the time, the students are effectively measuring the speed.

The string needs to be long enough for meaningful timing to be possible but not so long that carrying extra **mass*** requires so much air pressure that the balloon is close to popping.

The **friction** effect of the string is important. The balloons will travel a long distance on fishing line, so the difference between 1 pump of air and 2 pumps will be more obvious. Rough twine will stop the balloon in a shorter distance, making measurement error more significant.

Make sure the students understand that the balloon rocket does not stop because it "ran out of air". Newton's first law states that an object in motion will tend to remain in motion unless acted upon by an outside force. In theory, a balloon rocket on a perfectly horizontal string will keep going no matter how little air you pump into it. The balloon stops because the friction of the line (or **gravity**, if at an angle) is acting against the motion.

Encourage the students to discuss their results. This will reinforce the key competency *thinking* by providing opportunities for students to learn from their mistakes, improve their processes, and refine their conclusions.

* For bolded terms, see the glossary, pages 6–7

Points of entry: Mathematics

Scale is very important: 1 big pump of air is different from 2 little pumps. Prompt the students to think about how they can accurately measure and record inputs (how many pumps) and outputs (how far or how fast it went). Encourage them to use consistent units of their own devising. They could develop informal units or use this opportunity to learn or practise reading a scale for measuring the distance travelled along the string.

Introduce the idea of **function** (the same input should always yield the same output). In other words, 3 pumps of air should cause the balloon to travel about the same distance every time.

See if the students can define rules for the relationships they observe, for example, *How does the number of pumps relate to distance?* The students may be able to find a proportion or factor that enables them to predict distance in terms of pumps. Ask them to investigate how mass changes the relationships.

Points of entry: Science

Probe your students' knowledge of the scientific inquiry method (see page 5). Frame the investigation using scientific language: *What makes a trial a **fair trial**?* Use opportunities to introduce or reinforce vocabulary such as **hypothesis**, **prediction**, mass, and **force**.

Make sure that the students discuss why their predictions were accurate or inaccurate and that they generalise their results. Ask *What does your experiment teach you about the physical world?*

Note that if the same balloon is used for repeated trials, the elasticity of the balloon decreases with each inflation, which may affect the results. This is a good opportunity to discuss the acceptability of **experimental error**. An alternative is to use a new, identical balloon for each trial, but the problem then is that it will be difficult to attach the straw in exactly the same position so that the balloon lines up at the same angle. Again, this is an experimental error issue and may affect the results more than using the same balloon.

Activity Two

Answers

Investigation results will vary. When the string is horizontal (0º), the balloon speed is not affected by gravity because it's not moving up or down. As you change the angle, the balloon will start to go much faster down the string than up. Going up, the balloon has to fight gravity, but when it's going down, gravity gives it a boost. The higher the angle, the faster it goes down and the slower it goes up because more of the force is in the same direction as gravity.

Notes

Preparation and points to note

Consider using protractors or prepared cut-outs of different angles to simplify finding angles.

Depending on the length of the string, it may not be possible to reach a 45º angle. Either substitute a shallower angle or adjust the length of the string.

Students should run several trials of each configuration because there may be a lot of measurement error in the timing, especially when the rocket is moving with gravity. Set expectations about what makes a valid trial and emphasise the importance of repeatable results.

Points of entry: Mathematics

The students should develop and interpret tables and graphs to identify patterns. They could do this using a spreadsheet. Stress that they need to capture enough information in their tables to distinguish what they are testing in each trial. Encourage them to only change one **variable** at a time, for example, if they are increasing the mass, they should keep the angle the same to see the effect of increased mass on the time taken. Prompt the students to discuss why they should change only one variable at a time.

As part of exploring units, the students should discuss how they measure different aspects of the experiment, for example, using protractors to measure angles or using a stopwatch to measure seconds.

While accuracy is a goal, the identification of patterns or relationships is more important. **Outliers** can be the focus of useful discussion and may indicate that the students need to examine the way a result was obtained.

At this level, you need only elicit definitions in the students' language for how the **force of gravity** changes with angle. For example, at a shallow angle, there is only a small portion of gravity changing the motion, but at a steep angle, gravity has a bigger effect. Continue the exploration of functions and proportional relationships.

Make sure the students are aware of experimental error and how it can be minimised. You may want to get several groups to run the same trials and combine their data. Ask the students to work out the best way to combine the results of separate trials. Ask *What if more groups have tested 60º than 45º: can the different number of trials be combined the same way?*

Introduce the idea that force has a direction as well as a magnitude.

Depending on how fast the rockets travel, it might be necessary to discuss precision and accuracy. For example, *What if the rocket goes so fast that we can't click the stopwatch on and off quickly enough to time it accurately?*

Points of entry: Science

Reinforce use of the scientific inquiry method (see page 5). Ask the students to think about which trials they might have to throw out or repeat.

Discussion should focus on issues of fairness: Same balloon? Same type of balloon? Same number of pumps of air? Same distance travelled? Same lengths of straw? Same type of string?

In this activity, there may be three distinct motions: initial acceleration, a period of constant speed, and deceleration (slowing down). It's important that the students realise that a force causes a mass to accelerate. You could emphasise this by having students use straws to blow marbles across a desktop.

Reflective discussion could focus on other real-life applications, for example, doing work against gravity such as walking up a steep hill or rock climbing and the increasing effect of gravity as the angle becomes steeper.

Confront the students with the idea that there are many forces acting on the balloon at the same time and that these forces are stronger or weaker depending on the number of pumps of air and the angle. Advanced students can try to make freehand diagrams showing all the forces.

Ask *What further investigations might we do?* Prompt the students to develop additional hypotheses and test them.

Pages 4–6: Flying High

Mathematics and Statistics Achievement Objectives

- Measurement: Use linear scales and whole numbers of metric units for length ... weight (mass), angle ... and time (Geometry and Measurement, level 3)
- Statistical investigation: Conduct investigations using the statistical enquiry cycle:
  - gathering, sorting, and displaying multivariate category and whole-number data and simple time-series data to answer questions
  - identifying patterns and trends in context, within and between data sets
  - communicating findings, using data displays (Statistics, level 3)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Understanding about science: Appreciate that scientists ask questions about our world that lead to investigations and that open-mindedness is important because there may be more than one explanation (Nature of Science, level 2)
- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Physical inquiry and physics concepts: Explore, describe, and represent patterns and trends for everyday examples of physical phenomena, such as movement, forces, electricity and magnetism, light, sound, waves, and heat (Physical World, level 3)

Mathematics and statistics context

Students will:

- measure mass, angle, time, and speed
- find the relationships between mass, speed, and angle for a flying fox
- record data in tables and use graphical representations to interpret the results
- calculate average speed by dividing the distance travelled by the time taken.

Students should discover that:

- acceleration is not proportional to mass. Larger masses are pulled with more force, but the acceleration is the same.

Science context

Students will:

- ask questions and gather data to determine the relationship between the height (angle), mass, and speed of a flying fox.

Students should discover that:

- the motion of the flying fox is the result of the forces acting on it
- the acceleration of gravity (and hence speed) is proportional to angle: the steeper the slope, the faster the flying fox
- friction is a contact force that acts against motion
- the acceleration of gravity remains constant: all objects would fall at the same rate if no other forces were acting on them.

Related information

An interesting application of flying foxes with pulleys: http://homepages.ihug.co.nz/~Sspinett/Raoulhome/Chapter2/Raoul%20Island.The%20Island.html

Discussion of zip-lines (flying foxes): http://en.allexperts.com/e/z/zi/zip-line.htm

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Activity One

Answers

1. a.–b. Practical activity and discussion. Make sure that you are recording your data in an organised way. Averages and graphs will vary.

2. a. The graph shows the height of the string at each trial and how long each run took. From the results shown on this graph, you can see that the higher the height at the top end (the bottom height stays constant), the quicker the flying fox travels.

b. Gravity is a force pulling the flying fox towards the ground. From the trials, it looks like speed does have something to do with gravity – the further an object falls, the faster it goes! Gravity is always acting, so a person on a flying fox would experience the force the whole time they were falling. Forces change motion: either they speed the flying fox up or slow it down. In this case, as the flying fox falls, it speeds up. (If you were on an "extreme flying fox", released at a height of 175 m, you would reach a speed of 160 km/h.)

3. a. Your graph should look similar to Sarah's and clearly show that the steeper the angle, the faster the flying fox goes.

b. The more data you have on the same subject and experiment, the more reliable it will be and the more accurate your conclusions. Combining the data will "smooth" the graph and cancel out any unusual results (outliers).

Notes

Preparation and points to note

A flying fox is a very simple device, consisting of a pulley and a cable strung between two points. It can be used to carry a person in a harness. A flying fox relies on **gravity*** to move the pulley (and the person) from one point to the other. To work, one end of the flying fox must be higher than the other.

For the modelling, make sure there is enough uninterrupted space to stretch the lines without crossing. It may be best to do this investigation outside because it uses water (or sand) and the students also need to find suitable anchor points. Possible anchor points could be a wire fence, a fixed ladder, or objects in an adventure playground. Make sure that the pulleys are attached in such a way that they run smoothly. The students may need some practice using a stopwatch to time the passage of the milk bottle. (A 1 litre milk bottle full of water has a 1 kg **mass**.)

In case the students get over-excited about running their flying fox, establish or reinforce appropriate norms for working in new environments or with potentially dangerous equipment. Also consider the needs of individual students when grouping.

Consider setting up multiple lines at different angles in advance and have groups of students rotate around the circuit to gather their data. This avoids students having to repeat investigations to get more reliable data and enables discussion about validity because groups can compare and combine their data for the same investigation.

The graph is best done using a spreadsheet if the students have access to computers.

One aspect of the key competency *managing self* is that students learn to accept that they may feel confused while they gain new understanding. You may choose to emphasise this here.

With multiple trials at different heights, your students will be asked to record a lot of data. Encourage them to think aloud about how they might record the information, for example, "Hmm … How big will my table be? If I have 3 trials, that means 3, no, 5 columns because I need to record height and average as well. How many rows?"

Rather than trying to run a plastic milk bottle along the string, use a pulley to attach the milk bottle to the wire. (You can buy pulleys at any hardware store.) The milk bottle can be attached to the pulley with string through the handle.

The students need to take the height of the milk bottle into consideration at the lower end of the flying fox so that it doesn't hit the ground or collide with the peg. Collision can be avoided by having one student act as "catcher".

Note that if the peg in the ground remains the same horizontal distance from the anchor point (for example, a fence) each time one end of the string is raised, the length of the string will need to be increased. This will distort measurements and conclusions (hence the instruction in the students' book).

* For bolded terms, see the glossary, pages 6–7

Points of entry: Mathematics

In this activity, students measure time and speed, not distance. However, it is useful to ask your students to explain how speed relates to both distance and time. Ask *What does it mean to say someone is faster than someone else?*

Prompt the students to think about appropriate units. Using either informal units or a linear scale, they could measure the height of each attachment point. They could also measure mass, duration, length, and angle, selecting an appropriate measurement tool and units. While accuracy is desirable, the identification of patterns or relationships is more important.

While the height increment does not need to be a fixed value, it may be best to encourage the students to be systematic and increase the height each time by, say, 10 or 20 centimetres. Increasing height is the same as increasing angle, so encourage the students to also frame their thoughts in terms of slope and how slope increases. For example: *What if you increased the height of both the start and finish points? What if you moved the start and finish further apart or closer together?* Slope is the difference in height divided by the difference in length and is measured as a rate or angle. Note: The graph on page **5** of the students' book says "height". This could be taken as either the height from the bottom of the fence (as long as the height of the string on the peg at the lower end of the flying fox stays the same, as in the diagram) or the difference between start and finish heights. Ask your students to explain why the height of the string at the bottom of the flying fox is important when talking about how far the flying fox travels vertically.

Points of entry: Science

Activate the students' prior knowledge of height, angle, and speed. They will probably know that the higher a ramp is, the faster a bicycle will go down it. Introduce the idea of quantifying "how much faster" in order to make accurate predictions. Ask *Will a flying fox that is twice as steep go twice as fast?*

Refer to the scientific inquiry method (see page 5). Frame the investigation using scientific language: *What makes a trial a **fair trial**?* Data **outliers** are useful for discussion and can prompt students to consider methods as well as results. Different trials will probably go at different speeds. Make sure that the students are comfortable with the idea of variation, error, and chance factors (for example, the wind).

Use natural opportunities to introduce or reinforce vocabulary such as **hypothesis**, **prediction**, mass, and **force**.

Make sure that the students relate their results back to the conjectures made by Matthew and Gaytri about how to make a flying fox go faster.

Ask the students to apply their results to other contexts, for example, running down a hill.

Activity Two

Answers

1. **a**. Predictions and explanations will vary.
   b. Practical activity
   c. Hopefully, you'll see that the times are about the same no matter what mass you have in your flying fox. There may be some variation, but in general, adding more mass shouldn't speed it up.
2. The graph will be much more of a flat line than the height compared with time graph in **Activity One**. Changing the mass should not change the speed.

Notes

Preparation and points to note

Let the students experiment with trial runs to ensure that their flying fox runs freely. Sand or rice could be used (instead of water) to fill the bottles, but you will need measuring scales. The advantages of water are that 1 litre weighs 1 kg at normal temperatures and it's readily available.

Consider having objects of different mass on hand to help with misconceptions about gravity, mass, and falling speed, for example, a bowling ball and a tennis ball. (See the answers and support material for page **1**, Introducing Forces.)

Many people would predict that a heavier flying fox will run faster. However, the acceleration of gravity is constant, so all objects fall at the same rate. You can demonstrate this to your students by simultaneously dropping a heavy and a light object and asking them which one landed first. If there is no air resistance, they should both land on the ground at the same time. (However, the ***force* of gravity** is stronger on a heavy object than on a light one. To speed them both up by the same amount, gravity pulls harder on a heavy object – to get it moving – than on a light one.)

In the activity, make sure that the string doesn't start to sag because this will distort the data.

Points of entry: Mathematics

Check for experimental error: are the students "looking" for a particular result and throwing out data that doesn't fit their expectations?

Ensure that the students make the connection between the volume of water (1 litre) and the mass (1 kg).

Points of entry: Science

Challenge the students' misconceptions: *If you drop a cricket ball and a tennis ball, which lands first?* If possible, have them try this and discuss what happened.

Make sure that the students discuss their predictions before they try the experiment. You can relate this back to hypothesis and the scientific inquiry method (see page 5).

Encourage the students to discuss their results with other groups. This will reinforce the key competency *thinking* by providing opportunities for students to learn from their mistakes, improve their processes, and refine their conclusions.

Question what forces may be acting on the milk bottles (other than gravity) and how these may affect their speed.

Make sure that the students relate their results back to their predictions and that they try to develop reasons why their predictions were right or wrong.

Ask the students to apply their results to other contexts, for example, vehicles of different sizes going down a hill.

If possible, ensure that the whole class comes to a consensus on why height affects the speed but mass doesn't. For example, "Gravity pulls everything down. The higher the angle, the closer it gets to straight down, so gravity pulls it better. Gravity accelerates all masses at the same rate." Make sure that the students are not confusing force with acceleration – gravity accelerates all mass at the same rate, but the force of gravity is greater on larger masses, which is why they feel heavier.

Note: Some students might see the trend part-way through the experiment and wonder why they should bother continuing. Discuss how some effects might be non-linear, for example, the experiment might follow one pattern at first, and then the pattern changes. Confirming that a result is true throughout a range is also important.

Activity Three

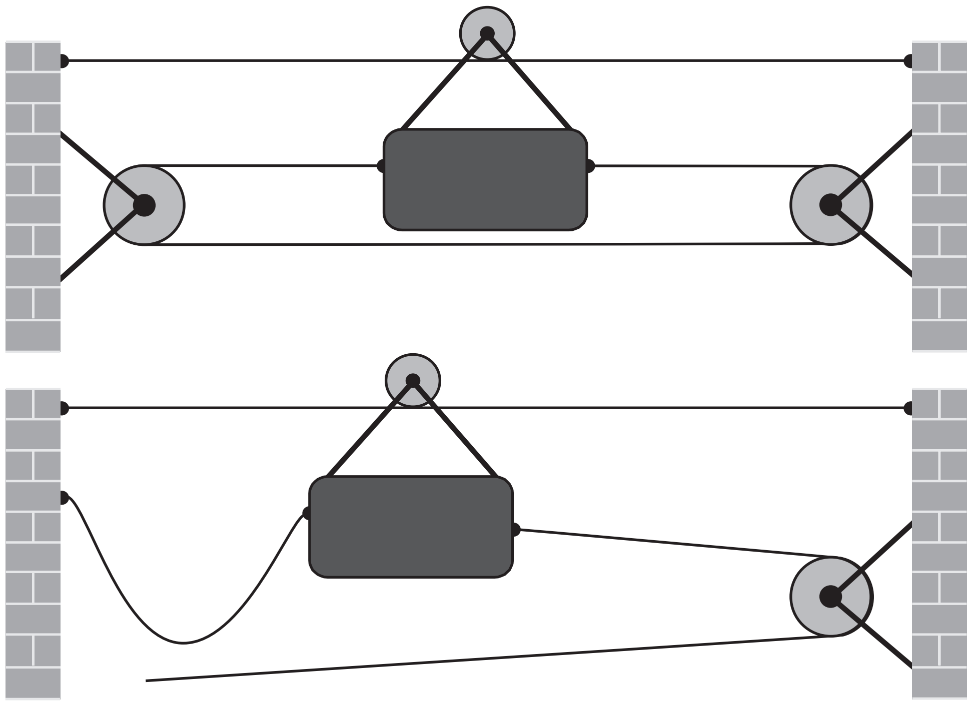
Answers

1. A person's weight (which is being pulled on by gravity) can have a big effect on a flying fox. A heavy weight can cause the cable to sag a lot, which will reduce the effect of gravity; that is, the cable will become more horizontal over the second half of the flying fox's travel. (However, on a very strong cable with no sag and no other factors such as strong wind, the difference will be minimal. A heavier person should reach the end about the same time as a lighter person because gravity pulls harder to get the heavier person moving at the same speed as the lighter person.)

2. A flying fox designer will have to be aware of the mass of the users, the length of the run, the tension on the cable, how often it's used (how much wear and tear), and how much maintenance it will need.

3. **a.** Practical activity

   b. **i.** You can arrange your pulleys to use less force by combining two or more pulleys together, for example, loop the string or cable around a pulley attached to the load and around another pulley attached to the wall, as shown in the diagram below.



   ii. The fewer pulleys you use, the less string you need because each pulley adds an extra loop of string or cable. The simplest arrangement is a single pulley to support the flying fox and a horizontal cable.

   iii. The cable is likely to be longer than twice the length of the classroom because you'll need at least one full loop of the classroom for a two-way pulley that can pull the load all the way to one end and then pull it all the way back, plus some extra cable to go around each of the pulleys.

Notes

Preparation

For question **3**, the students will need more (and possibly stronger) string (or rope) and pulleys. You may wish to make groups larger to minimise materials. A 1 kilogram weight could simply be 1 litre of water.

Points of entry: Mathematics

Cable sagging will give non-linear behaviour, in other words, the flying fox will speed up or slow down at different points because of the sag. Challenge the students to describe the behaviour in different parts of the cable. For example, they might say, "In the beginning, it's really steep, but then it sags and the weight goes slower as it travels down the cable because the sag makes the cable path less steep."

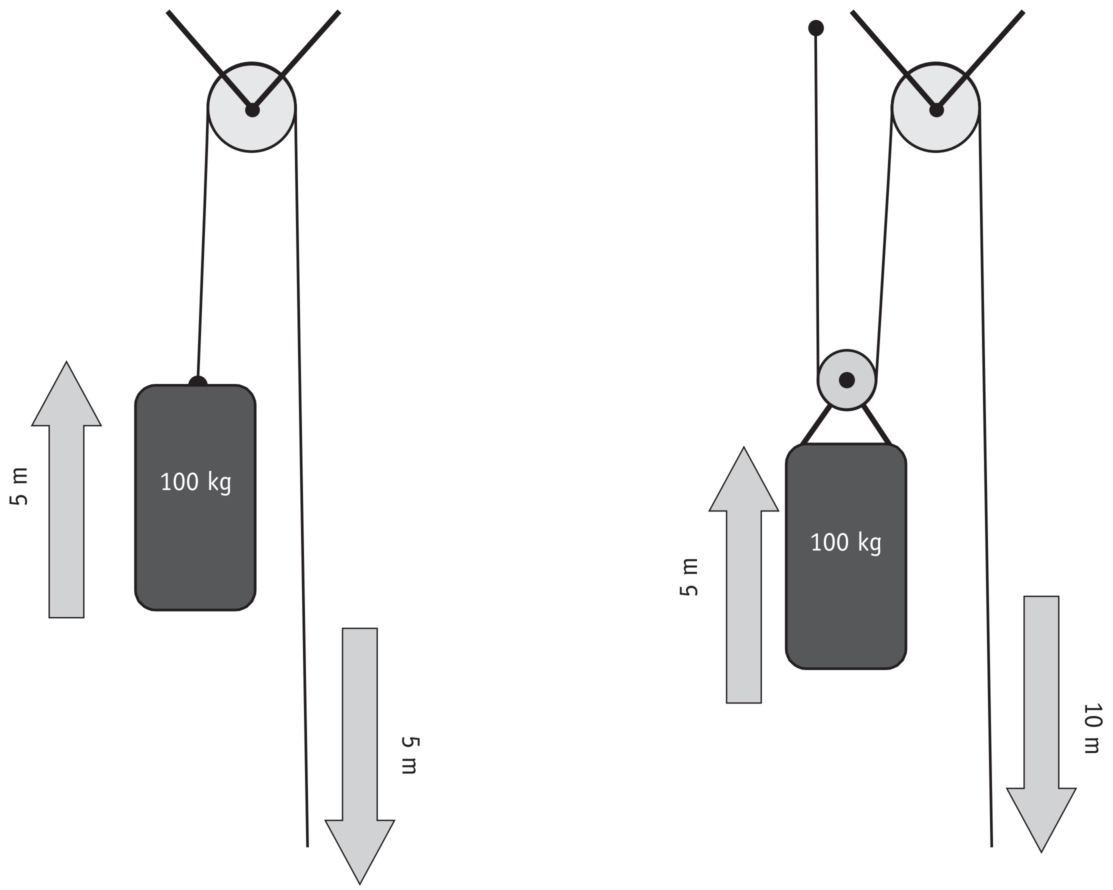
Encourage the students to frame their questions in a mathematically testable (quantifiable) way. For example, when they are investigating pulley systems, ask *How will you measure force?* Such critical thinking is an important aspect of the key competency *thinking*.

A calibrated spring or a scale attached to one end of the pulley cable will give a good reading of the force exerted.

Points of entry: Science

Other variables that could be investigated could be changing the mass of the object being moved, the tension in the cable, or exploring aerodynamics using different shapes. The Making Better Sense books have an investigation planner at the start that students could use.

A two-way pulley system allows the user to swap force for distance. The pulleys make it easier to lift a load but increase the distance the rope travels by the same factor. To lift a 100 kg weight 5 m with a single pulley, the free end of the rope travels 5 m. If you use 2 pulleys, the same load will feel like 50 kg, but the free end of the rope will travel 10 m (see diagram). (100 x 5 = 50 x 10)



Making Better Sense of the Physical World, pp. 116–117, has a useful section on pulley systems.

Pages 7–9: High or Low?

Mathematics and Statistics Achievement Objective

- Measurement: Create and use appropriate units and devices to measure … length (Geometry and Measurement, level 2)
- Statistical investigation: Conduct investigations using the statistical enquiry cycle:
  – posing and answering questions
  – gathering, sorting, and displaying category and whole-number data
  – communicating findings based on the data (Statistics, level 2)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Understanding about science: Appreciate that scientists ask questions about our world that lead to investigations and that open-mindedness is important because there may be more than one explanation (Nature of Science, level 2)
- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Physical inquiry and physics concepts: Explore, describe, and represent patterns and trends for everyday examples of physical phenomena, such as movement, forces … (Physical World, level 3)

Mathematics and statistics context

Students will:

- measure weight, depth, and salt concentration (which is effectively a measure of density)
- find the relationship between the force involved in buoyancy and water density
- find the relationship between the weight of a boat and its floating depth (for a given hull profile)
- record data in tables and use representations to interpret the results.

Students should discover that:

- buoyancy force is a function of the weight of water displaced. Heavier boats need to displace more water to stay afloat (they ride lower). Boats with wide hulls float high in the water because each centimetre of depth displaces a large volume.

Science context

Students will:

- make a prediction about density (salt concentration) and buoyancy
- ask questions and gather data to determine the relationship between salt concentration and buoyancy (determined by measuring the submerged depth of the boat or the height floating above water).

Students should discover that:

- buoyancy is relative to density. (Salt water is more buoyant than fresh water because the mass of the salt dissolved in it makes it denser.)

Related information

Making Better Sense of the Physical World, pp. 120–122

Building Science Concepts: Book 37, *Floating and Sinking*; Book 38, *Understanding Buoyancy*

Connected 3 1998: "The Boat Race"

Connected 1 2002: "Prince Zak and the Wise Frog"; "The Paddling Pigs of Fakaofo"

School Journal, Part 4 Number 2, 1999: "The Waka Ama Nationals"

Sample lesson on buoyancy: www.sciencetechnologyaction.com/lessons/30/Imdo-lesson.pdf

Concrete boats: www.space.com/businesstechnology/technology/space_concrete_010601.html
www.concreteships.org/history/

Plimsoll lines: www.britannica.com/EBchecked/topic/464810/Plimsoll-line

The New Zealand Institute of Physics: www.nzip.org.nz

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Activity One

Answers

1. There are several factors that affect buoyancy:
   - The forces acting on the object. Gravity is pulling the object down, and water is pushing it up. If the object's weight is balanced by the upthrust, then the object will float.
   - The volume of the object. Density is related to volume. If two objects have the same mass and one takes up more space, it has a lower density because it has a bigger volume for the same mass.
   - The density of the object compared with the density of the water. If the object is less dense than the water, it will float; if it is more dense, it will sink. Salt water is more dense than fresh water, so things float better in salt water.

   These factors are closely related, and they combine to determine whether the object floats or sinks.
2. Ideas will vary. You may think that the salt in the water "holds" the boat up in some way.

   The toy boats will float at different levels depending on their weight, the temperature of the water, and how much salt is in the water. They will float lower in fresh water than in salt water. Boats also float lower in warm water (which is less dense) than in cold water. Warm water will float on top of cold water if the warm water is gently poured onto the cold water and they are not mixed together.

   Salt water is more dense than fresh water, so it pushes harder against objects floating in it. To float in salty water, objects need to displace less water than they do in fresh water.

   This is a difficult concept: a fish can float but will be under the water; an iceberg floats but is partially above and partially below the water surface.
3. **a.** The Plimsoll line indicates the safe loading level of a boat. The markings on the Plimsoll line indicate the safe levels in various circumstances, such as fresh or sea water.

   b.–c. Practical activity

   d. Findings will vary, but as more salt is added, each boat should float higher in the water and the depth reading should decrease. The pattern should be the same for different types of boats as long as each boat is tested in all the different concentrations. A graph would help to show the trend.

   e. A general statement might be: "The more salt, the higher the boats float."

Notes

Preparation and points to note

This activity could get messy, so set appropriate rules and anticipate what might happen if water gets splashed. Make sure the students know how to switch stations at appropriate times. The activity could be done outside or a tarpaulin could be used to protect the floor.

If there are no boats available, groups could use plastic cups or yoghurt pottles for boats and add washers (or modelling clay or marbles) until they sit low in unsalted water. Plastic cups could be marked with their scale on the inside, using waterproof marker pens. The cups or bottles need to have vertical sides and start with enough weights in them so that they float vertically.

Groups may need to use multiple (identical) boats, especially if waxed-paper boats get soaked.

The students will need to use enough water and salt to ensure that there is an appreciable difference in **buoyancy*** between each basin. If all the boats are light and float high in fresh water, sand or weights such as metals washers, coins, or marbles can be added to make them sit lower in the water, making the effect of the changes in **density** more apparent.

The scale marks on the side of each boat should be at regular intervals.

* For bolded terms, see the glossary, pages 6–7

Points of entry: Mathematics

This activity provides multiple opportunities for talking about measurement and **experimental error** (for example, the salt may or may not dissolve completely). The students need to create and use their own scales to measure how high their boat sits in the water.

If the irregular shape of the boats makes it difficult to see the trend, repeat the experiment using cylindrical plastic bottles or test tubes, weighted so that they float upright.

The activity also provides an opportunity to focus on the key competency *using languages, symbols, and texts* because it encourages students to build new knowledge, find ways to describe their thinking, and use tables and graphs to display their findings.

Points of entry: Science

The students will have many ideas about why things float. Use questioning and example–counter-example inductive strategies to refine their ideas. For example, if students think kayaks sit lower in fresh water than sea water because the surrounding body of water is smaller, ask *What would happen in a small creek compared with a large river?*

Huihana, Taine, and Jacob use the scientific inquiry method (see page 5) to investigate. Point out features of the method, including making a **fair trial** and having **controlled variables**.

Have the students compare their results with other groups and make conjectures about why results differ.

Unpack the idea of density. Density is the mass per unit of volume. If the density of the boat is less than that of the water it displaces, it floats. If the density is greater, it sinks. You can increase the density by increasing mass or lowering volume.

An object floats in water when the upthrust (the **weight** of the displaced water) balances the object's weight. (Note that, in this case, we talk in terms of weight and not mass because buoyancy is a **force** and weight is a measure of the **force of gravity** acting on a mass. For an explanation of mass and weight, see the answers and support material for page **1**, Introducing Forces.) Adding more salt to the water increases the mass and hence the density of the water (the volume hasn't changed), which means that the upthrust is greater for the same amount of displaced water.

One way to engage students in thinking about mass and volume with respect to density is to use boats made from paper or aluminium foil. A boat shaped out of waxed paper or foil will float. If you crumple it up so that it has a very small volume, it will not float nearly as well.

Extensions include investigating, in general, why things float. For example, *Steel boats are very heavy. Why do they float?* (A steel boat occupies more volume than a solid chunk of steel of the same weight. The force of the water pushing the boat up is greater than the weight of the boat [the force of gravity pulling it down]. The larger the volume, the more the upthrust.)

Investigation

Answers

1. The Dead Sea in Israel is the saltiest body of water in the world. The Aral Sea is also extremely salty. Evaporation causes the salt concentration in a body of water to increase because some of the water goes into the atmosphere as water vapour but the salt remains.
2. Findings will vary. Adding mass to water will increase its density. Eventually, the water becomes saturated and nothing more will dissolve in it. Muddy, dense water is more buoyant than clear, fresh water.

Notes

Points of entry: General

See the answers for comment on very salty seas. Students could try out their ideas about substances such as dirt and clay by adding measured amounts to water and stirring until dissolved.

Investigations should be structured so that students can draw meaningful results. Prompt the students to apply the results of their investigation. (This can be linked to thinking in flexible ways, an aspect of the key competency *thinking*.)

The students' discoveries do not have to be expressed in numbers in order to activate mathematics and science concepts. For example, a relationship can be as simple as "The muddier the water, the higher a boat floats." Transfer these ideas to other contexts: *On a humid day, the air is less dense because water vapour is less dense than dry air. Will it be easier or harder for planes to take off?* (Harder, as the less dense air provides less lift)

Activity Two

Answers

1. Discussion and practical activity
2. **a.** Steps will vary.

   b. Adding weight in the centre of a boat lowers the whole boat. Spreading the same amount of weight evenly along the length of the boat has the same effect. Adding mass to one end of the boat tilts that end into the water and raises the other end.

   c. Answers will vary. You may be able to talk over your results with a waka ama team or organisers and make recommendations about the number of crew, their weight, their position in the waka, and the effect on speed of being in salt or fresh water. In general, crew should sit evenly along the length of the boat because concentrating the weight in one section of the boat will make it hard to steer.

Notes

Preparation and points to note

The students could use aluminium foil and iceblock sticks to make waka ama models, which they could float in buckets. They could add modelling clay cubes to represent people of different sizes. Narrow, waka-style boats are less stable than other types of boats and are therefore useful for illustrating the effects of the distribution of weight. Encourage the students to explore positioning in their model boats as well as the effect of adding more "people" and to use sketches or photos when documenting their results. Groups could then share their findings with each other and identify relationships.

Points of entry: Mathematics

The students will need to devise appropriate scales and record data systematically. They need to think about what **variables** they are investigating, for example, distance from the prow (the front part of the boat). Ask them to explain which of these variables are **independent** and which are **dependent**.

Prompt your students to make appropriate representations of their data, whether in diagrams, graphs, tables, or other models.

Points of entry: Science

Challenge the students to justify whether or not their findings are valid for a real waka. *How do real scientists work? What are you doing that is similar to how real scientists work?*

Reinforce the ideas of the scientific inquiry method (see page 5), scale, experimental error, and accuracy. Ask the students to generalise their results as much as possible.

Pages 10–11: See-saw Antics

Mathematics and Statistics Achievement Objective

- Number strategies: Use a range of additive and simple multiplicative strategies with whole numbers ... (Number and Algebra, level 3)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Participating and contributing: Explore and act on issues and questions that link their science knowledge to their daily living (Nature of Science, level 2)
- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Communicating in science: Begin to use a range of scientific symbols, conventions, and vocabulary (Nature of Science, level 3)

Mathematics and statistics context

Students will:

- gather and record data and use tables to identify patterns and relationships
- identify the relationship between the relative positions of the effort and load when balanced.

Students should discover that:

- turning force is a function of weight x distance from the fulcrum – in other words, the longer the lever arm, the less force is needed to lift a weight on the other side of the fulcrum
- the relationship between distance from the fulcrum of different weights is inverse (if there is twice as much weight on one side, it needs to be twice as close to the fulcrum to balance).

Science context

Students will:

- build their scientific vocabulary
- gather data and look for patterns and relationships using levers.

Students should discover that:

- a lever is an example of a simple machine
- a machine can be used to change the direction and magnitude of a force
- levers have a point where a force is applied (effort), a fulcrum (the turning point), and a point where it is felt (load).

Related information

Building Science Concepts: Book 59, *Bikes*

Making Better Sense of the Physical World, pp. 105–115

www.enchantedlearning.com/physics/machines/Levers.shtml for moving pics of levers

www.ptgo.org/pdfs/garrykrinsky.pdf

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Figure It Out, *Proportional Reasoning,* levels 3^{+}–4^{+}: Dog Torque

Activity One

Answers

1. Rongo needs to move nearer the middle of the see-saw until he reaches a position where he and Kiri balance each other. In order for the see-saw to balance, the turning forces on each side of the see-saw must be equal. (This means the distance from each child to the middle of the see-saw multiplied by that child's mass has to be the same.) If Rongo's mass is twice that of Kiri, Kiri needs to be twice as far from the fulcrum (see the diagram in **Activity Two**).

Notes

Points of entry: Mathematics

Question your students about their mathematics strategies: *How do you know where to put Rongo compared with Kiri if Rongo weighs twice as much as Kiri? Are you adding or multiplying to predict where to balance the see-saw? What if there are several children on each side of the see-saw: how would you arrange them so that they balance?*

Introduce the idea of **inverses***, for example, 2 and $\frac{1}{2}$. The **weight** and the distance from the **fulcrum** are inversely proportional: if the weight on one side is double that of the weight on the other, it will balance it at half the distance from the fulcrum.

Although the students should use an informal scale for Rongo and Kiri, encourage them to quantify distance, for example, ask *If Rongo is half a metre from the fulcrum, where should Kiri sit?*

Points of entry: Science

Students will have prior knowledge of how see-saws work. Encourage them to think up their own experiments: "What combinations of students will balance? Where? How could a see-saw be used to weigh things?"

Activity Two

Answers

1. **a.** Practical activity. Your table should look similar to the table below if you are using a 30 cm ruler with the fulcrum in the middle (at 15 cm). The second column illustrates the pattern by showing the distance from the fulcrum of 2 washers.

Distance (cm) from the fulcrum of 1 washer	Distance (cm) from the fulcrum of 2 washers (to balance)
15	7.5
10	5
5	2.5
4	2

   b. The single washer will be twice as far from the fulcrum as the 2 washers. In other words, distance from the fulcrum x weight (washers) is the same on both sides.

   c. When 3 washers are used on one side, they are placed $\frac{1}{3}$ of the distance from the fulcrum compared with the single washer.

2. **a.** To balance a long crane arm, the counterweight on the shorter side must be heavier than the load being lifted. The turning force of the counterweight x the length of the short arm has to equal the length of the load arm x the load.

   b. Answers will vary. Examples might include a balance beam or balancing on a high wire at the circus, a scale for measuring weight, the axle of a trailer towed by a car or truck, or the keel of a sailing boat.

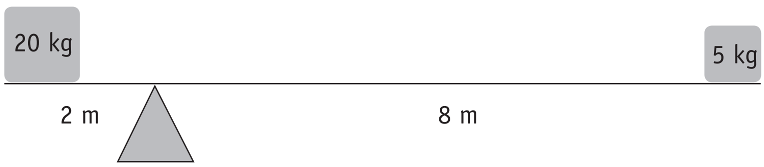
Notes

Have the students use light plastic or wooden rulers or they will get incorrect results when the fulcrum is not in the centre of the ruler because the different weights of the ruler on each side of the fulcrum would balance out some of the weight of the washers.

The position of washers on each side of a fulcrum will always be *relative to the fulcrum*. Watch out for students who might be moving the washers *and* the fulcrum in order to find balance. This will result in measurement error. Avoid such measurement errors by asking the students not to move the fulcrum during their investigation. The **turning force** (often called torque) is always dependent on the distance from the fulcrum as well as the weight.

Note that **force** and turning force are not the same. Turning force is force x distance. What this means is that a small **weight** on one side of a fulcrum can balance a large weight on the other side of the fulcrum if their turning force is the same, but their weights (and corresponding **force of gravity**) will still be different.

* For bolded terms, see the glossary, pages 6–7



Points of entry: Mathematics

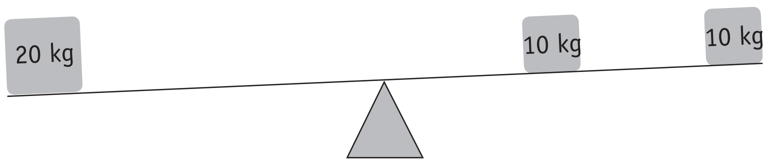
This activity revolves around the idea of equality of products. Ask the students how they will work out where to place multiples of washers (weights). For example, *If you have 3 washers on one side and 1 washer on the other, how do the distances compare?*

It's important that the students realise that they need to measure distances from the fulcrum, not from the end of the ruler. Question your students about where the "zero" on the scale of the see-saw or ruler is. In other words, *If you put the washer on the 30 centimetre mark, are you interested in the distance from zero or the distance from the fulcrum?*

Points of entry: Science

The science language and concepts in this activity will be new to students: exposure to a wide range of experiences is one of the aims of the key competency of *using languages, symbols, and texts*.

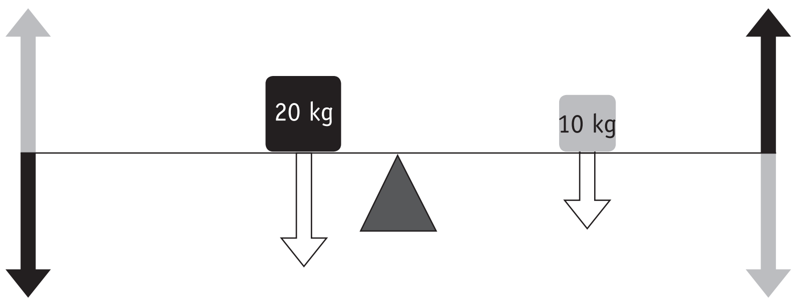
Activate what the students have learned about force and differentiate between force and turning force. Have them consider this unbalanced situation:



The force of gravity (weight) on the masses on both sides of the fulcrum is the same, but the turning force is not.

This activity defines fulcrum and the simple lever machine. Simple machines transfer the location and/or the direction of a force. Ask *How does a lever change the direction of a force?* Simple machines include the wheel and axle, screw, pulley, lever, and wedge or inclined plane. Ask: *How is a lever like a pulley? How does a screw change the direction of a force?*

Deepen the students' thinking about forces by having them draw diagrams showing the relative size and direction of forces. In the diagram that follows, the white arrows indicate the force of gravity, the black arrows indicate the turning force of the 20 kg weight, and the grey arrows indicate the turning force of the 10 kg weight. Notice that the turning forces are equal, and therefore the see-saw is balanced, because the 10 kg weight is twice as far from the fulcrum as the 20 kg weight.



Activity Three

Answers

1. Arms and legs act as levers when kicking a ball, boxing, dancing, swimming, and so on. When you lift anything, the tendons and muscles in your arm cause your bones to act as levers, with your joints as fulcrums.
2. a. i. When pulling out a nail, the fulcrum is at the bottom of the u-bend. When used as a lever, the fulcrum is wherever you support the bar (by resting it on something).

      ii. The fulcrum is the 2 hinges at the top where the swing pivots.

      iii. A diving board has its fulcrum at the end connected to the stand.

   b. The fulcrum of a canoe paddle is the point where the paddle is in the water (which is why the blade of a paddle is wide – the width slows the movement of the paddle in the water so that the boat moves forward; think about what it would be like paddling with a stick!).
3. The fulcrum for each object is:
   - scissors: at the bolt where the two blades connect
   - nail clippers: at the kink in the top lever; at the opposite end of the second lever
   - wheelbarrow: at the axle of the wheel.

   The levers for each object are:
   - scissors: one blade and handle
   - nail clippers: the part you push down and the top part of the cutter
   - wheelbarrow: the strut from the wheel to the end of the handle.

Notes

Points to note

The fulcrum of a lever isn't always obvious. For example, a fishing rod is a lever where the fulcrum is the end of the handle, the **effort** is on the handle, and the **load** is on the tip. It's easier to visualise this when the person fishing is in a harness and the butt of the rod is secured. A shovel is a lever where the fulcrum is in different positions depending on how it is used. For example, if you're using a shovel to lift a load, the back hand is the fulcrum.

Points of entry: Science

Levers are classified by the relative positions of load (weight), fulcrum, and effort. If the load is on one side of the fulcrum and the effort is on the other, it's a class one lever, like a see-saw. Class two levers have the fulcrum on one end and the effort on the other, for example, a stapler. Class three levers have the fulcrum on one end, the load on the other, and the effort in the middle, like a pair of tongs.

Challenge the students to identify other situations that use levers and fulcrums and ask them to come up with examples for the different classes of levers. The students will need to listen actively to each other and build on others' ideas. The key competency *relating to others* involves recognising when to compete and when to co-operate.

Pages 12–13: Skateboarding Theory

Mathematics and Statistics Achievement Objectives

- Position and orientation: Use a co-ordinate system or the language of direction and distance to specify locations and describe paths (Geometry and Measurement, level 3)
- Measurement: Use linear scales and whole numbers of metric units for length ... weight (mass), angle ... (Geometry and Measurement, level 3)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Participating and contributing: Explore and act on issues and questions that link their science knowledge to their daily living (Nature of Science, level 2)
- Communicating in science: Begin to use a range of scientific symbols, conventions, and vocabulary (Nature of Science, level 3)
- Physical inquiry and physics concepts: Explore everyday examples of physical phenomena, such as movement, forces ... (Physical World, level 2)

Mathematics and statistics context

Students will:

- use the language of geometry to describe position, direction, and angle
- relate angle of lean to radius.

Students should discover that:

- turning circle is proportional to angle of lean
- cone spacing is proportional to turning circle.

Science context

Students will:

- explore the relationship between shifting weight and changing direction on a skateboard
- develop an explanation of how the skateboard wheel mount (truck) transmits these changes.

Students should discover that:

- the skateboard truck contains simple machines: a lever and two axles
- a machine changes the direction and magnitude of a force.

Related information

Building Science Concepts: Book 59, *Bikes*

Making Better Sense of the Physical World, pp. 105–115

The mechanics of skateboard turning: www.quadskating.com/skates/roller-skate-trucks.htm

How a skateboard works: www.exploratorium.edu/skateboarding/skatedesigntruck.html
www.ehow.com/how-does_4564503_a-skateboard-work.html

Simple machines in a skateboard (not about turning, but a useful extension):
www.drskateboard.com/pdf/simple_machines_lever_fulcrum.pdf

An alternative truck that illustrates how the wheels move relative to the board:
www.tarantulatrucks.com/trucks.html (compare photos 5 and 6 in the gallery)

How skateboards are made, with a good truck illustration: www.madehow.com/Volume-6/Skateboard.html

A useful extension on centripedal force: www.teachervision.fen.com/tv/printables/tv00092_s3.pdf

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Activity One

Answers

1. **a.** Rameka bends his knees and moves his chest and arms forwards and backwards to shift his weight. When your weight shifts, the heavier side of the board starts to tilt down, like a see-saw.

   b. i. As your weight shifts, that side of the truck moves backwards with respect to the deck (board) and turns slightly inwards to the centre. The skateboard turns towards the "down" side of the board.

   ii. Your speed should be about the same, but direction will change.

2. **a.** Practical activity. The shortest distance between the cones will depend on your skill and the quality or other features of the board.

   b. The tighter you can turn, the closer the cones can be. (Loose trucks that lean at a hard angle will turn better than stiff trucks that keep the deck relatively level.) The faster you travel, the more difficult it will be to turn in time to go around the cones.

Notes

Preparation

Establish or reinforce appropriate rules for safe, non-disruptive skateboarding and how best to share skateboard time. As with any group activity, carefully consider the needs of individual students.

Points of entry: Mathematics

Encourage the students to think about shapes. Although they will set up the cones in a straight line, when they lean on the skateboard, the board describes **arcs*** of circles. Ask them to sketch (on paper or in the air with their hands) the shapes they make as they decrease the distance between cones.

Encourage the students to look for the relationship between the **radius** of the circle and the position of the deck of the skateboard. For example, ask: *Does a sharper angle of the deck produce a smaller or larger circle? How does the shortest distance relate to the geometry of the skateboard – that is, how steeply can you lean the board?*

Ask the students what other relationships they notice. Prompt them to compare different groups and different boards: *Are wider boards easier to turn? Why?*

Have the students record more than one **variable**, for example, distance between cones, rider, angle of lean, and time. Ask them to think about which variables are important and which probably don't affect cone distance, and then to test their thinking.

Points of entry: Science

Students need to have opportunities to explore how to use their **weight** to change direction and to discuss, consider, and attempt to explain why this happens. Give the students opportunities to closely examine the truck and have them use drawings and diagrams, both their own and those of others, to make sense of how it transmits **forces**. All this encourages reflection and evaluation, which are aspects of the key competency *thinking*.

Encourage the students to use scientific vocabulary. Ask: *What forces are acting on the skateboard? What forces are acting on the rider so that they keep their balance? How do these forces affect the motion of the truck?*

* For bolded terms, see the glossary, pages 6–7

Activity Two

Answers

1. a–b. Practical activity. Your observations will be most useful if you record your data in a systematic way.

2. a. The size of the smallest circle will depend on the skateboard, but it will be when the board is tilted the most.

   b. You could ride a skateboard in circles around the line of cones in **Activity One**. The closer the cones, the smaller the radius of the circle.

3. a. The wheels move forwards and backwards because the vertical axle in the truck converts the tilt of the board into a rotation of the wheel axle.

   b. A skateboard truck is like a see-saw because it contains levers that rotate around fulcrums. For example, the deck or board is like a see-saw, with the middle of the truck as a fulcrum. Shifting your weight to one side is like putting more weight on one side of a skateboard – the other side tilts up.
   A skateboard truck is different from a see-saw because it contains more than one lever, fulcrum, and axle and it changes the direction of the force from up-and-down to side-to-side.

Notes

Preparation and points to note

Circles with a radius of 4 metres take up a lot of space. You may want to have the groups overlap their circles.

Students may not think about recording their data in a systematic way. For them to comment meaningfully on what they have observed in question **1**, they will need to find an efficient way to record this data. Consider providing a chart for recording angle of lean, radius, truck turn angle, and radius for each circle. (Large wooden protractors will allow students to measure angle easily.)

Points of entry: Mathematics

When the students have recorded angle of lean, truck turning angle, and radius for each circle, challenge them to make predictions based on their data. For example, they could estimate the "smallest circle" instead of finding it by experimentation. See if they can estimate what angle will produce a given radius or vice versa. They could also plot angle versus radius.

To get the most out of this activity, students will need to work co-operatively, initially in pairs. This gives them an opportunity to develop the key competency *participating and contributing*.

Have the students compare and contrast the circles and the line of cones. For example, for different circles, they could put two cones just outside and one just inside the circle. Ask *How does the distance between the cones relate to radius?*

Points of entry: Science

Discuss why modelling is not always an accurate reflection of real life. Ask: *Why are you able to navigate a tighter circle pushing the board than standing on the board? Why is it more difficult to ride a skateboard around a small circle than to push it with your hands?*

Have the students compare how a skateboard steers with how other vehicles steer. Ask: *Instead of a truck, what if the front wheel was connected to handles, like the front wheel of a scooter or bicycle? What really determines how large a circle a skateboard can make?* (It's the turn-in of the wheels, not the lean of the board.)

Pages 14–15: High Wire

Mathematics and Statistics Achievement Objectives

- Patterns and relationships: Connect members of sequential patterns with their ordinal position and use tables, graphs, and diagrams to find relationships between successive elements of number and spatial patterns (Number and Algebra, level 3)
- Position and orientation: Use a co-ordinate system or the language of direction and distance to specify locations and describe paths (Geometry and Measurement, level 3)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Participating and contributing: Explore and act on issues and questions that link their science knowledge to their daily living (Nature of Science, level 2)
- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Physical inquiry and physics concepts: Explore everyday examples of physical phenomena, such as movement, forces ... (Physical World, level 2)

Mathematics and statistics context

Students will:

- identify the relationship between the relative positions of weights, the centre of gravity of the system, and stability.

Students should discover that:

- the turning force (moment around the fulcrum) produced by gravity is a function of weight × *horizontal distance* from the fulcrum.
- as the arms get closer to horizontal, they effectively become longer:
  - if a lever arm slopes down, lifting that side increases the horizontal length of the arm and therefore increases the turning force
  - if a lever arm slopes up, lifting that side (making it more vertical) decreases the horizontal length of the arm distance and decreases the turning force.

Science context:

Students will:

- investigate the balancing of turning forces
- model a system in equilibrium.

Students should discover that:

- the acceleration of gravity is constant: it accelerates all parts of a system the same way
- objects have a centre of gravity, which can be located inside or outside an object
- when turning forces are in equilibrium, an object is balanced
- when an object is balanced, the centre of gravity is directly above or below the fulcrum
- if the centre of gravity is below the fulcrum, gravity acts as a restoring force; the system will automatically return to equilibrium when pushed out of balance because gravity will tend to rebalance it
- if the centre of gravity is above the fulcrum, gravity acts as a destabilising force; a moving object will come to rest at a position where its centre of gravity is as low as possible (the minimum energy position).

As well as fostering *thinking*, the challenges in High Wire will build new knowledge and require the use of precise language and appropriate tools – all part of the key competency *using language, symbols, and texts*.

Related information

Building Science Concepts: Book 51, *Standing Up*, especially activity 3: Testing Our Balance, p. 15

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Man on Wire: Philippe Petit: http://en.wikipedia.org/wiki/Man_on_Wire and www.imdb.com/title/tt1155592/

Pictures of tightrope walkers: www.timboucher.com/journal/wp-content/uploads/2008/04/chinese-tight-rope-walker.jpg http://blog.nj.com/ledgerupdates_impact/2007/11/large_petit.jpg

How to find the centre of mass: www.sciencefair-projects.org/physics-projects/find-centre-of-gravity.html or http:/teams.lacoe.edu/documentation/classrooms/judi/forces/activities/gravity.html

Balancing and centre of mass activity: www.csiro.au/helix/sciencemail/activities/balancingglass.html
Balancing spoon and fork on a glass: www.wonderhowto.com/how-to/video/how-to-balance-a-spoon-and-fork-on-a-match-on-a-glass-162897/

Background information: Activities One–Three

Teacher understanding

These background notes apply to all three activities. (Note that bamboo kebab sticks, which are cheap and easy to obtain, work well as skewers.) High Wire follows very closely from See-saw Antics (pages **10–11**) and the notes for that activity should be read in conjunction with these.

The key question in **Activity One** is question **2c**: "What is it that makes this object balance?" Although this activity introduces trigonometric concepts, students at this level only need to understand the effect of angle on vertical and horizontal distance.

The mathematics behind high-wire balancing is quite complex. To help the students, you don't need to understand everything, but what you teach needs to be correct so that students don't have false ideas that they carry through to higher levels. Use the following true or false list and notes to help you understand the ideas.

True:

- Any object will balance, no matter how strangely it is shaped.
- An object doesn't have to be **symmetrical*** to balance – you can balance an object (such as a see-saw) that has a lot more **weight** on one side.
- You *can* balance a space rocket upside down – it's just very, very difficult! (Although it is easier to balance on your feet, it is possible to balance on your head!) To balance, the **fulcrum** must be located at, directly above, or directly below the point where the **turning forces** of either side are equal.
- Balance is about turning forces, not overall **forces**. Even a heavy elephant can balance.
- Objects whose **centre of gravity** is above the fulcrum tend to be unstable. The turning forces are destabilising because tilting the object increases the weight on that side, which increases the turning force (weight x distance).
- The lower the centre of gravity is below the fulcrum, the more stable a structure will be.

False:

- Things with more weight are more stable.
- Force is the same no matter in what direction it's exerted. (False because force is directional.)

Activity One

Answers

1. Practical activity
2. a. Your space rocket will wobble if you move your finger, but if the centre of gravity is below the fulcrum, it will balance when the movement stops.

   b. It can be pushed or moved quite a large distance about the fulcrum, but if the centre of gravity is below the fulcrum, it will balance when the movement stops.

   c. The weights on the ends of the skewers work to restore balance. When the space rocket is disturbed, weights on one side lift up and weights on the other side go down. In this space rocket, the skewers are angled down, so the turning force on the high side will increase and the turning force on the low side will decrease. The weights on the high side (or those further out on a see-saw) move further away from the centre of gravity and hence provide a bigger turning force that corrects the tilt.
3. a.–c. Investigation and discussion

* For bolded terms, see the glossary, pages 6–7

Notes

Preparation and points to note

A firmer material such as clay works better for the blobs than a softer material: the skewers and blobs are more likely to stay in place.

Gravity doesn't "pull more" on any piece of the space rocket. Gravity accelerates every **mass** in the rocket the same way, although more mass will have more **force** because force = mass x acceleration of gravity. (Note that mass is the correct term here – weight is the force exerted on the mass.) Gravity is directional: it always pulls "down". Turning force is also directional; it's caused by forces perpendicular (at right angles) to the lever (in this case, the skewer). The closer a skewer is to horizontal, the larger the turning force will be for a given mass because the force of gravity is multiplied by a longer horizontal distance.

This seemingly simple activity about balance can lead deep into geometry and trigonometry. However, at this level, you only need to encourage the students' intuition. Don't let them get "bogged down" by complexities.

This activity and the one that follows provide opportunities for students to work with a diversity of classmates. By being actively involved in a group with a common interest and focus, they are developing skills that apply to the key competency *participating and contributing*.

Points of entry: Science and Mathematics

A space rocket with perfectly horizontal skewers (like Peter's arms in the illustration) can balance but, like a see-saw, it is not very stable. Ask *What happens when it tilts?* Most students will know that if you push one side of a see-saw down, it will keep going down until it hits the ground (even though the turning forces are theoretically balanced and it should therefore be able to hold its position). Ask *What's really going on?*

The turning force of a weight depends on its horizontal distance from the fulcrum; as the high side goes up, the weight moves further away from the fulcrum, and as the low side goes down, the weight gets closer to the fulcrum. A small weight a long way out can balance a larger weight closer in. As with a see-saw, as the high side moves up, its force increases; as the low side moves down, its force decreases.

One way of highlighting this is to attach strings to the bottom of the rocket body and to the blob on the end of each skewer. As the rocket tilts, the string on the low side approaches the centre; the string on the other blob moves further away.

Reinforce the idea that force has both size and direction. Gravity is always pulling "down", so turning force is being applied vertically through the centres of the blobs at the end of each skewer.

Ask: *What would happen if you angled the skewers upwards? Why is a space rocket like this difficult to balance?* (The reason is that if one side tilts down, the horizontal distance of the weight from the fulcrum *increases*. The higher up the weight on the left, the less turning force it contributes.)

Encourage the students to use mathematical vocabulary to describe their space rockets and how they balance, for example, angle, slope, horizontal, vertical, distance.

Prompt students to make the connection between the skewers of the space rocket and the two ends of a see-saw. Introduce the idea of centre of gravity. The space rocket will balance when the centre of gravity is directly above or below the fulcrum, no matter at what angle the skewers are placed. Ask: *If Peter* (in the illustration) *is balancing on one leg and sticks out the other leg, what does he do to stay balanced?*

Activity Two

Answers

1. Practical activity
2. Questions will vary. Possible questions may be:
   - Why is one rocket more stable than another?
   - How many legs can I add to my rocket and still have it balance?
   - If I add a weight to one side, do I have to add an equal weight to the other side to make my rocket balance?
   - How does the angle of the skewer and the position of the weight affect the way my space rocket balances?

Notes

Preparation and points to note

If you use kebab sticks as skewers, the students can easily cut these to length using scissors.

As with any investigation, try to deter the students from going straight into action. Encourage them to pose a **hypothesis** and plan their activity.

Points of entry: Mathematics

A 3-dimensional space rocket requires different spatial thinking compared with a 2-dimensional see-saw. Use this different thinking to explore the idea of X-Y-Z axes or 3-dimensional figures in general. Ask the students to describe the different movements of their space rocket and to draw diagrams or record the relative positions of the different weights using mathematical language. Ask: *How would you describe your space rocket so that someone else could build an identical one? How is one space rocket different from another?*

Challenge the students to achieve equality (balance) with unequal weights by varying the effective length of the skewers, not just through length but also through angle.

Points of entry: Science

If the students haven't done so already, prompt them to think hard about the see-saw nature of the space rocket and how skewer angle affects horizontal distance of the weight from the fulcrum.

As noted in the support material for **Activity One**, gravity always pulls in the same direction, but changes in angle alter the amount of turning force produced by gravity. Encourage the students to predict which blob is providing the most turning force. In other words, before they attempt to balance a rocket by adjusting weight, length, and angle, ask them to plan their adjustment rather than use simple trial and error.

The centre of gravity is harder to identify when objects are not symmetrical or uniform. Push the students to locate the centre of gravity (see the diagram below) on their rockets by, for example, moving the fulcrum or hanging the rocket from strings attached at different points. Question them about the centre of gravity of a balanced see-saw where the fulcrum is not in the middle: *What would that look like? How large a weight should be on each side?* Challenge the students to locate the off-centre fulcrum for an irregularly-shaped space rocket.

When the students have tried out their ideas, encourage them to compare their thinking. Ask them to justify any new ideas to their classmates, especially if they have reached different conclusions.

Activity Three

Answers

1. Practical activity

2. a. Practical activity. The most stable walker will be one with long skewers placed at an acute angle (less than 90°). (The more acute the angle, the lower the centre of gravity and hence the more stable. Similarly, the longer the skewers, the lower the centre of gravity and hence the more stable.)

   b. Gravity keeps the walker balanced because it's pulling down on each skewer. As a skewer becomes more horizontal (parallel to the ground), gravity causes more turning force because gravity is always pulling down vertically. When the walker tilts, the skewer closer to the horizontal provides more turning force, so it tends to return to vertical.

c. Very wide walkers will be less stable because there isn't much difference in turning force between when the walker is balanced and when it is slightly tilted. Very tall, narrow walkers will be very stable because even a small tilt moves the skewers a long way sidewards, like someone sliding a long way further out on a see-saw. Because the skewer on the high side moves further from the fulcrum, that side goes back down, restoring the balance.

d. A walker is like a see-saw because the skewers of the walker are like the two ends of a see-saw and the centre of the tightrope is the fulcrum. The longer the skewers, the greater the force produced for a weight, just as a person on a see-saw produces more force by sitting close to the end.

3. Discussion will vary.

Notes

Preparation and points to note

Thin string such as a builder's line works well for this activity. If students experience difficulty positioning their tightrope walker on the thin string, a small blob of clay at the end of the central skewer will increase the contact area.

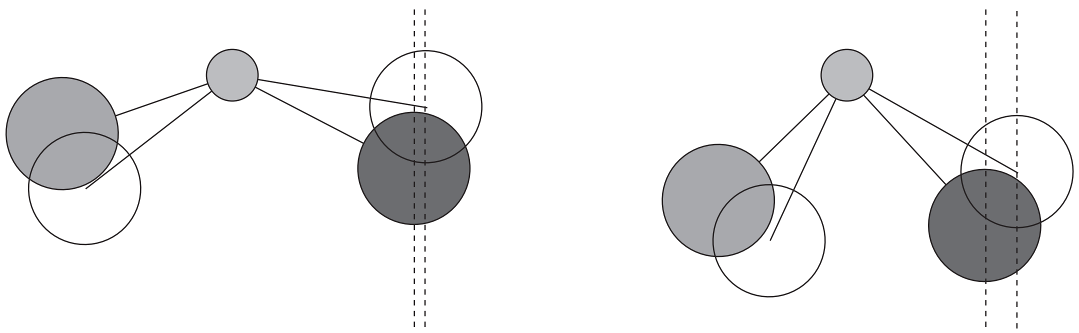
Make sure there is some variation between the tightrope walkers. The students could use coloured markers or glue to personalise their walkers.

Points of entry: Science and Mathematics

This activity reviews the ideas introduced in activities **One** and **Two** and asks students to demonstrate their understanding of turning force by applying their ideas to new shapes. Use this activity to reinforce understanding of turning force and centre of gravity or as an additional opportunity to ensure that all students can explain why some shapes are more stable than others.

Students can be the most effective teachers of other students. Try to identify which students have a good grasp of the principles in **Activity One** and pair them with students who are still struggling with the ideas.

Ensure that the class as a whole comes to appropriate conclusions about the tightrope walkers. The most stable tightrope walker will have long legs at near vertical angles because a steeper leg gives a larger change in horizontal distance for the same amount of tilt, and hence a larger restorative turning force. In other words, the steep-legged walkers will return to a balanced state faster. For example, the tightrope walker on the left side of the diagram below has its grey and black legs at relatively shallow angles.



When it tilts, the centre of each weight moves only a small distance, as shown by the vertical lines going through the centre of the black weight and the clear circle representing the position of this weight after tilting. The tightrope walker on the right has its skewers for the grey and black weights at steeper angles. For the same amount of tilt, the centre of each weight moves a larger horizontal distance, represented by the gap between the dotted lines.

Pages 16–18: Swing Time

Mathematics and Statistics Achievement Objectives

- Statistical investigation: Conduct investigations using the statistical enquiry cycle:
  - gathering, sorting, and displaying multivariate category and whole-number data and simple time-series data to answer questions
  - identifying patterns and trends in context, within and between data sets
  - communicating findings, using data displays (Statistics, level 3)
- Statistical Literacy: Compare statements with the features of simple data displays from statistical investigations or probability activities undertaken by others (Statistics, level 2)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Participating and contributing: Explore and act on issues and questions that link their science learning to their daily living (Nature of Science, level 2)
- Physical inquiry and physics concepts: Explore everyday examples of physical phenomena, such as movement, forces ... (Nature of Science, level 2)

Mathematics and statistics context

Students will:

- gather, sort, and display data on weight, length, and period (the time it takes to swing forwards and backwards [1 swing])
- using that data, communicate findings and make predictions.

Students should discover that:

- the longer the length of the rope, the greater the period for each swing.

Science context

Students will:

- explore and trial ideas using models
- investigate the period (and hence the frequency) of pendulums.

Students should discover that:

- a swing on a rope is an example of a pendulum
- the period of a pendulum is related to the length of the rope but is not affected by the weight on the end of the rope.

Related information

Video of different mass pendulums: www.fearofphysics.com/Pendulums/pendhl.html

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Activity One

Answers

1. Answers will vary, but even if the girls start at different positions, their swings won't synchronise.
2. You might suggest aspects such as the weight of the person on the swing, the length of the rope, the position of release, how much force is applied to push the swing, and how much body movement the person on the swing puts into swinging forwards and backwards. (You'll be investigating some of these ideas later.)

Notes

Preparation

Structured play on real swings is a good introduction. For example, ask the students to try to swing forwards and backwards in time with each other. They could try this: with and without body movement, someone just letting them go from a height, or that person giving them a push-off at the start.

Points of entry: Mathematics

Introduce or reinforce the idea of **variables***. Ask *What are all the things we can change when we are using swings?* Applying creative thinking to a practical context like this is a good opportunity to focus on the key competency *thinking*.

Points of entry: Science

Activate the students' prior knowledge about swings through open-ended questioning, for example, *What do you know about swinging?*

Students could answer question **1** by experimenting on swings (see Preparation) or you might want to have them to move a model (which they are asked to do in question **2**). This investigation could be carried out using a real swing, but models will be more easily managed by a large number of groups and take less time. Modelling is common practice for scientists. Ask *How would a scientist look at a swing set?* (Note that model swings will not be able to take into account questions that the students may have about the effect of body movement. The activities in Swing Time investigate length and **weight** without variables such as body movement, but you could have some very interesting discussions with your students after the trials.)

Generalise a swing as a pendulum. Ask: *What is a pendulum? Where else do we see pendulums?*

Remind the students about **gravity**: unless you get a push or pump your legs, swings are powered by gravity. Discuss with them the effect of getting a push or pumping with their legs. (Both these actions result in extra **force** being exerted. The extra **energy** will give added height but will not make any difference to the time taken for 5 swings – the swing will just move faster as it covers the extra distance.)

Activity Two

Answers

1. **a.** Practical activity. Your plans about the process need to be reasoned and manageable. For example: "How many times will we repeat each weight?" You might also think about fairness, for example: "Would it be fair if, for the first trial of a weight, the person on the swing used body movement and for the next trial they didn't?"

   b. Repeating the experiment a number of times for each different number of weights will make the findings more valid. You will get a fairly accurate result if you find the average (mean) because although you might make a mistake on one trial (for example, not clicking the stopwatch at the right moment) you probably won't make the same mistake every time.

2. **a.** Results will vary. Your table should show similar times for 5 swings for every trial, no matter how many weights you use.

   b. Although the choice of graphs will vary, they should have 2 variables, for example, as in a scatter plot. Be careful of the scale: the computer may automatically scale it so that it looks like there is a lot of variation, but the variation will actually be very small. Results should produce a roughly horizontal line, showing that weight does not affect the period of the swing if all other factors are kept constant.

3. Adding more weight will not change the period of a swing if everything else is kept constant. Your graph should show that weight has no real effect on swing period.

Notes

Preparation and points to note

As with any group activity, carefully consider the needs of individual students. Ensure that the weights used are identical.

Remind the students that they should time their model for 5 swings and that 1 swing is 1 movement forwards and backwards.

* For bolded terms, see the glossary, pages 6–7

Encourage the students to think about why they need to put all the weight on the same part of the string. Weights spread up and down the string will have varying effects on the **period** of the pendulum swings, in other words, they would be testing weight and length at the same time.

Students may think that weight will affect the period of the swings. Let them discover that it doesn't.

Points of entry: Mathematics

This activity is a good example of the use of the statistical enquiry cycle: problem, plan, data-gathering, analysis, conclusion. Point out how this process could be applied to any investigation that involves the comparison of variables.

Tables and graphs are ways of representing information and ideas and, as such, are part of the key competency *using language, symbols, and texts* that can be applied to this activity. The *thinking* needed for evaluating results is another relevant key competency.

Explore **fair trials** and ideas of fairness by using seemingly unfair methods, for example, starting from obviously different starting points or pushing the swing forwards rather than just letting it go. (In the first example, the students should find that it makes no difference to the periods recorded. In the second, it affects the speed of the first "swing".)

In question **2**, the students decide how to represent their data. Encourage them to argue for or defend their choice of graph. Ask *Why do we use graphs and tables for data?* (It's to help see patterns more easily and clearly.)

Use the multiple trials to discuss **experimental error**. Ask: *Why might two trials have different results? What might cause error?*

Ask the students to apply their knowledge to other settings. For example, *What would shortening the pendulum of a clock do?* (Shortening the length of the pendulum will increase the number of swings per minute and so speed up the clock.)

Points of entry: Science

Statistical and scientific inquiries follow the same method (see page 5). Repeat scientific vocabulary like **hypothesis**, fair trial, and conclusion. Make links to other investigations that the class has performed using the scientific inquiry method.

Encourage groups to compare their results. Ask: *Are the results similar? For example, do two groups draw the same conclusion? Why would this be important?* As an alternative, the class could collate the averages (means) from all groups and graph them and then discuss overall class results. Discuss how this could give a more valid picture, for example, by having a larger sample size or more repetitions.

Activity Three

Answers

1. **a.** Practical activity. Counting the time for 5 swings when the string is at its full length will give you comparison data to use in the other trials of different lengths. (You may have discovered from **Activity Two** that Ngawai was not right in what she initially thought. If you pull the string or rope further back, the swing will go higher at the other end but will still take the same time for 5 swings at that rope length as it does from further in.)

   b. Results will vary. (It's good practice to use the same weight for each trial.) You can measure the string and change the length by halving and quartering it, by using multiples of its length (2 x, 3 x, and 4 x the length), or by shortening or lengthening it an equal amount each time and recording the number of swings per minute.

   c. Graphs will vary. However, your graph should show that when the string is full length, the time for 5 swings is less. The longer the string is, the longer it takes to go back and forth.

2. a. The connected points need to pass through the origin (0,0) to show that there is no swing (no time taken; the period is 0) when the rope on the swing has no length.

b. Your graph should be a curve because the relationship between time taken for 5 swings and rope length is not a straight line. (For example, the time for the half length is not half the time for the full length and the same would apply to any points in between.)

c. Estimates will vary, but the time for 5 swings for twice the full length should be more than double. (Imagine the curve on your graph as it gets steeper – where might it end up for twice the full length?)

Notes

Preparation and points to note

The students will probably want to use their rulers to measure rope length. Consider asking them to find fractions like three-quarters without a ruler, for example, by looping a string in half, then half again, mark the quarters, and reduce the length by one-quarter. (Note that the true length of the pendulum in each case includes the weight on the end.)

In this activity, students need to make sense of information, their own experiences, and the ideas they come up with, so the key competency *thinking* is applicable. For example, the students are not asked specifically to do more than one trial for each length here, but they have done this in **Activity Two** and discussed why, so encourage discussion of this for **Activity Three**. (It is obvious from Lucy and Ngawai's graph that they did more than 1 trial for each length.)

Interestingly, students could vary the weight in different trials of length without affecting the result. However, good practice requires that they keep the weight the same (as noted in the answers).

Points of entry: Mathematics

In this activity, Lucy and Ngawai don't average the trials in their graph; rather, each trial is represented as a separate data point. Have the students compare and contrast this approach with using a single average (mean) point to represent all the data gathered at each length.

The relationship between period and string length is not linear. Doubling the length of the string won't make it go exactly twice as fast. The students will need to estimate the effect of different string lengths. Question **2** introduces the opportunity to talk about linear behaviour (straight lines) and non-linear (curves). For example, the area of a square is not linear because if you increase the length of its side, the area increases exponentially.

Side of a square	Area
1	1
2	4
3	9
4	16

[***Note to teachers.*** Pendulums are based on the geometry of the circle. Increasing the length of the pendulum is the same as increasing the **radius** of the circle described by the path of the weight on the pendulum end. In other words, lengthening the pendulum increases the distance the pendulum travels on each swing according to the relationship between radius and circumference ($C = 2\pi r$).]

Points of entry: Science

Students may question why a longer pendulum takes longer to do 5 swings. The relationship between length and speed is complex. Put simply, longer pendulums take longer to do 5 swings because they travel a greater distance both vertically and horizontally. Longer pendulums fall further and therefore accelerate more due to gravity, but they also have a much longer **arc** to travel.

Pages 19–21: Zoom, Zoom!

Mathematics and Statistics Achievement Objectives

- Statistical investigation: Conduct investigations using the statistical enquiry cycle:
  - gathering, sorting, and displaying multivariate category and whole-number data and simple time-series data to answer questions
  - identifying patterns and trends in context, within and between data sets
  - communicating findings, using data displays (Statistics, level 3)
- Measurement: Use linear scales and whole numbers of metric units for length ... weight (mass), angle ... (Geometry and Measurement, level 3)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Investigating in science: Ask questions, find evidence, explore simple models, and carry out appropriate investigations to develop simple explanations (Nature of Science, level 3)
- Participating and contributing: Explore and act on issues and questions that link their science knowledge to their daily living (Nature of Science, level 2)
- Physical inquiry and physics concepts: Explore everyday examples of physical phenomena, such as movement, forces ... (Physical World, level 2)

Mathematics and statistics context

Students will:

- measure mass, height, and distance and find the average of multiple trials
- record data in tables and interpret the results with the help of representations
- identify the relationship between mass or height and the distance travelled.

Students should discover that:

- distance rolled is a function of mass x speed with which the car comes off the ramp
- variables can be independent, dependent, or controlled
- taking the average (mean) helps to identify the central tendency of a trend. In other words, average is a useful measure of centre.

Science context

Students will:

- make predictions about the motion of objects.

Students should discover that:

- the force of friction is what slows the car down
- the pull of gravity accelerates all masses at the same rate. Larger masses don't go faster but, because they are harder to stop, they tend to go further.

Related information

Building Science Concepts: Book 42, *Marbles*

NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Activity One

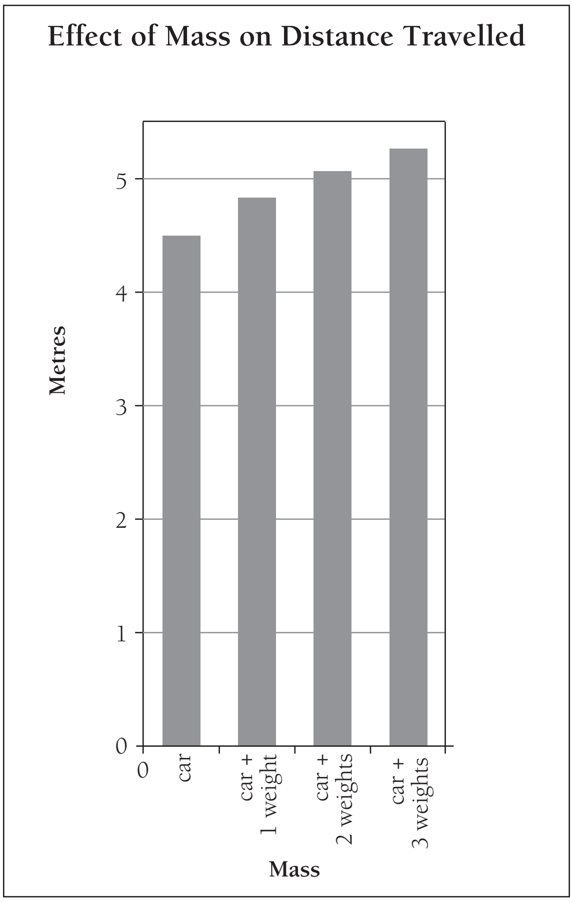
Answers

1. Ideas will vary. (Try to explain why you think your ideas will make a difference.)

2. **a.** Practical activity

b. The dependent variable is the distance travelled. The independent variable is the thing changed in each trial (in this case, mass).

c. Graphs will vary. However, each graph should show that heavier cars go further after they leave the ramp. A possible graph is:



3. In real life, a heavy car will be harder to slow down or stop than a lighter car travelling at the same speed (because the heavier car has more mass).

Notes

Preparation and points to note

Make sure the students have enough uninterrupted space for the model cars to roll long distances without interruption. A smooth surface works best; carpets create **friction***.

The students could do the graphing on a computer spreadsheet programme.

In this activity, students need to make sense of information, draw on their own experiences, and debate their ideas, all of which use and further develop the key competency *thinking*.

The students will have prior knowledge, ideas, and misconceptions about **mass**, height, and distance. Encourage them to test and argue their ideas and to find evidence or counter-arguments via their investigations. Students need to be explicitly taught the norms of mathematical argumentation and that it's the ideas that are competing and being evaluated, not them.

Although the students may know by now that **weight** doesn't affect speed (see Flying High, pages **4–6**), they may not realise that mass does affect **momentum**. Weight affects speed down the ramp (the pull of **gravity**), but it's the mass (and friction) that affects speed after a car leaves the ramp. Heavier cars have more momentum, so they travel further, given the same amount of friction. Note that in the Swing Time activity, the pendulum speed was also not affected by weight, but heavier pendulums have more momentum and continue to swing for a longer time.

Points of entry: Mathematics

All the aspects that the students suggest will be **variables**. Prompt them to consider other variables and classify them as **independent** or **dependent**.

* For bolded terms, see the glossary, pages 6–7

Make sure that everyone understands the definitions of independent, dependent, and **controlled variables**.

Measurement should be discussed in conjunction with accuracy, units, and error. Instead of grams or kilograms, the students can use informal units for mass, for example, identical small weights. Make sure they understand why the units must be uniform.

Discuss why averages (means) are useful when analysing data. It is unwise to rely on the results of just one measurement because of conditions and human error. Discuss averages in relation to activities that are naturally prone to variation, for example, traffic, air temperature, attendance, or driving speed, where any one measurement will not give you a good picture of overall conditions.

Ask the students to think about why they are asked to graph their results and about what type of graph to use. *What advantages does a graph have over a table? Why do we use different representations?*

Points of entry: Science

Remind the students what it means to "think like a scientist". This activity reintroduces the scientific inquiry method (see page 5). Ensure that the students are comfortable with the cycle of **hypothesis**, design of experiments, data gathering, and conclusion.

Ask: *What factors will affect distance? How can we test their effect fairly?* Have the students invent experiments, for example, ask *How could you test whether wheel size affects how far a car travels?* For each test, prompt the students to determine the independent and controlled variables. (The dependent variable for these tests should always be the distance travelled.)

Challenge the students to justify why they think a particular variable may be important. This will reveal much about their science understandings. For example, air resistance increases with speed, but the cars will probably not go fast enough to make air resistance important. Variables that could spark students' thinking include starting location, wheel size, axle size, lubrication, wheel shape, wheelbase, and the car's length, width, and **centre of gravity**.

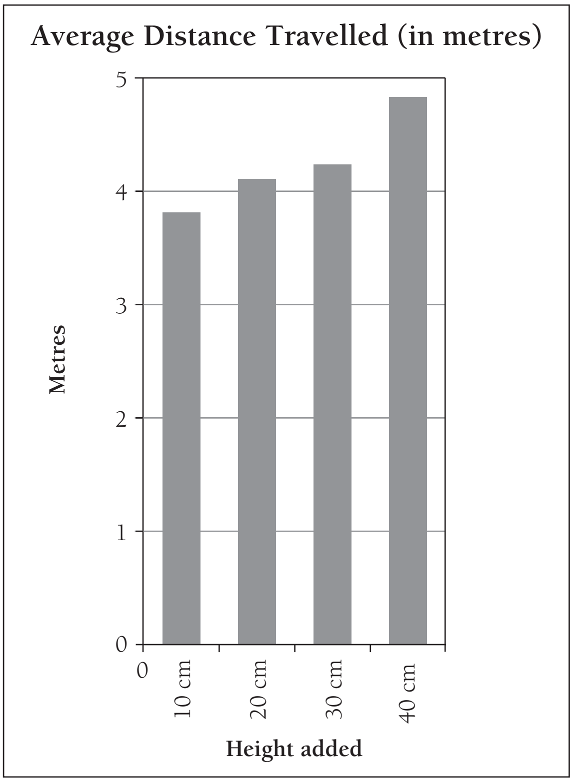
Prompt your students to identify what makes their investigation "scientific".

Relate their results back to their initial predictions: *So did mass have an effect?* Cognitive science tells us that people learn better when they think about how they learn. Ask *How did the structure of the investigation help you make conclusions?* Ask the students to think critically about how they pursued their investigation and what changes would have improved it.

Activity Two

Answers

1. Practical activity. Your graph should show that the higher ramps caused the car to travel further. For example, if you used up to 4 extra 10 cm blocks, your graph should show a similar pattern to this:



2. Different groups should have similar shaped graphs. However, the actual values will depend on factors such as the length of ramp, car, friction, and extra blocks used.	**3.** A heavy car on a high ramp should go furthest.

Notes

Preparation and points to note

Changing the height will change the angle at which the ramp meets the ground. Cardboard and tape will help round any sharp angles or sudden drops. Make sure that the students have a way to secure the top of the ramp at different heights, for example, by propping the ramp up with different numbers of the same blocks (or books).

Ask the students to think about factors such as why it's important to start the car at the same spot for every trial and where the location of zero is on their horizontal scale of distance.

This is a natural opportunity to mix up groups so that the students work with a diversity of classmates. By being actively involved in a group with a common interest and focus, they are developing skills that apply to the key competency *participating and contributing*.

Points of entry: Mathematics

Link back to the ideas of independent, dependent, and controlled variables. On graphs, the mathematical convention is for the independent variable to go along the horizontal axis.

Ask: *What other variables are contributing to the results? How do different cars behave on a ramp that is kept at the same height?* Remind students to think about sources of error.

Points of entry: Science

The activity calls for multiple trials at different heights in order to get more data points (and hopefully, better accuracy).

Have the students relate their results back to their initial predictions: *Did height have an effect?*

Guide the students to think about weight and height together. The combination of the heaviest car on the highest ramp should clearly go the furthest. Have the students compare intermediate cases, for example, a light car on the highest ramp versus a heavy car on the lowest ramp.

As noted for **Activity One**, encourage the students to realise that the **force of gravity** pulling on a car is its weight (going down the ramp), but once the car is off the ramp, it is its mass that determines how far it will roll.

Pages 22–24: Gearing Up

Mathematics and Statistics Achievement Objectives

- Number knowledge:
  - Know basic multiplication and division facts
  - Know fractions … in everyday use (Number and Algebra, level 3)

Mathematics standards. The approaches and thinking that students demonstrate as they engage with these tasks and problems can provide evidence in relation to the mathematics standards.

Science Achievement Objectives

- Communicating in science: Begin to use a range of scientific symbols, conventions, and vocabulary (Nature of Science, level 3)
- Participating and contributing: Explore and act on issues and questions that link their science knowledge to their daily living (Nature of Science, level 2)
- Physical inquiry and physics concepts: Explore everyday examples of physical phenomena, such as movement, forces … (Physical World, level 2)

Mathematics and statistics context

Students will:

- gather data about gears
- identify and represent patterns using gear ratios
- predict the force required to turn a set of gears.

Students should discover that:

- a large cog meshed with a small cog is hard to turn but makes the small cog rotate many times
- a small cog meshed with a large cog is easy to turn but doesn't rotate the large cog much.

Science context

Students will:

- build their scientific vocabulary around the ideas of gearing and mechanical advantage.

Students should discover that:

- gearing multiplies the force that is applied, giving mechanical advantage and so making work easier
- work and energy are conserved with the use of gears (work = force x distance, so less force requires a longer distance).

Related information

Building Science Concepts: Book 59, *Bikes*
Connected 3 2008: "Jumping for Joules"
Making Better Sense of the Physical World, pp. 105–115
School Journal, Part 4 Number 3, 2004: "Pumping the Pedals"
Animation of cogs: http://redhareproductions.blogspot.com/2007/11/blog-post.html
How cycle gears work: www.exploratorium.edu/cycling/gears1.html
How gears work: http://science.howstuffworks.com/gear.htm
How to use gears on a bike, including how to number from 1st to 18th gear: http://bicycleuniverse.info/eqp/gears.html
The New Zealand Institute of Physics: www.nzip.org.nz
NZ Physics Teachers' Resource Bank: www.vuw.ac.nz/scps-demos/

Activity One

Answers

1. a.–b. Practical activity. You should notice that you win lots of points if your cog is much smaller than the other player's cog.

2. Practical activity. Your table will vary, depending on which cogs you pick. Here are some possibilities:

Game	Number of teeth on the first cog	Number of teeth on the second cog	Number of turns the second cog makes when the first cog is turned once	Number of turns the first cog makes when the second cog is turned once
1	24	12	2	$\frac{1}{2}$
2	32	24	$1\frac{1}{3}$	$\frac{3}{4}$
3	36	24	$1\frac{1}{2}$	$\frac{2}{3}$
4	18	36	$\frac{1}{2}$	2

3. The number of turns is related to the number of teeth. If the first cog has twice as many teeth as the second cog, the second cog turns twice as many times as the first cog.

4. a. Adding a third cog will reverse the direction because every alternate cog turns the opposite way.

   b. The number of cogs does not affect the ratio, which depends only on the first and last cog in a train.

Notes

Preparation and points to note

While **ratio*** is at the core of these two activities, the emphasis here is totally on building on students' intuitive understandings (which are based on prior experience) through practical activities. You could introduce ratio notation, but only as a convenient means of labelling a particular combination of cogs or sprockets. The students are not required to use ratios in calculations.

These activities require students to interact, share ideas, and work effectively with others, so the key competency *relating to others* is a suitable focus for development.

Points of entry

There is no need to introduce the game in **Activity One** – the students will very quickly realise what is going on. They will probably then actively feel for the smallest available cog, so any randomness will go out of the selecting. To circumvent this, you could randomly assign a number to each cog and have the students blindly select one of the numbered pieces of paper.

Ask the students to explain what they have learned from this simple game. Most importantly, they should realise that it is not the absolute size of the cogs that matters (the cog that wins one round may lose the next) but which of the two is bigger or smaller, and by how much. Some will realise that the number of teeth is a convenient way of measuring and comparing the cogs. From here, it is a short leap to the realisation that, if two cogs are meshed and one has double the teeth of the other, for every time the large cog turns, the small cog turns twice.

Activity Two

Answers

1. Answers will vary. Gears make it easier to cope with different conditions or terrain, such as riding uphill or long distances.

2. a.–c. Practical activity. Results and graphs will vary. Compare your graph with those of other classmates and discuss what overall patterns they show.

   Your graph should show that lower gear ratios turn the rear wheel less and higher ratios turn the wheel more. Your graph should slope up and to the right because as you increase the ratio, you increase the number of times the wheel goes around for 5 turns of the pedals.

* For bolded terms, see the glossary, pages 6–7

3. **a.** Practical activity

 b. **i.–ii.** Practical activity. The easiest gear should be 1st gear, with the smallest sprocket at the front and the largest sprocket at the back. The hardest gear should be top gear, with the largest sprocket at the front and the smallest in the back.

 iii. Higher gears require more force than lower gears because in a high gear, you are moving the wheel further for each turn of the pedal. In other words, the rear wheel is doing more work, so you need to apply more force!

4. **a.** A cyclist going up a hill uses a low gear ratio because the effort required to pedal is greatly reduced. The trade-off is that there is less forward speed, so it takes longer to get from point A to point B.

 b. If in gear when going down a hill, you would use a high gear ratio. Normally, you would "freewheel" downhill, using your brakes to slow down when necessary.

 c. Discussion will vary, especially if you do some practical experiments. How hard you want to work will be a factor. In general, you would start off in an intermediate gear so that it's easy to get the bike moving and then shift up to go faster. Starting in a high gear requires a lot of force on the rider's part. Starting in a low gear means that the rider pedals very fast but travels very slowly.

Notes

Preparation and points to note

This activity needs to be done in pairs. If it's done as a whole-class activity, you will need to plan ahead to ensure that on the day there is at least one bike (with gears) for every two students. Establish protocols for the use of the bikes. These should cover safety considerations. They should also cover the conditions (including permission and care taken) on which non-owners may use others' bikes.

Refer also to the relevant notes for **Activity One**.

Points of entry: Mathematics

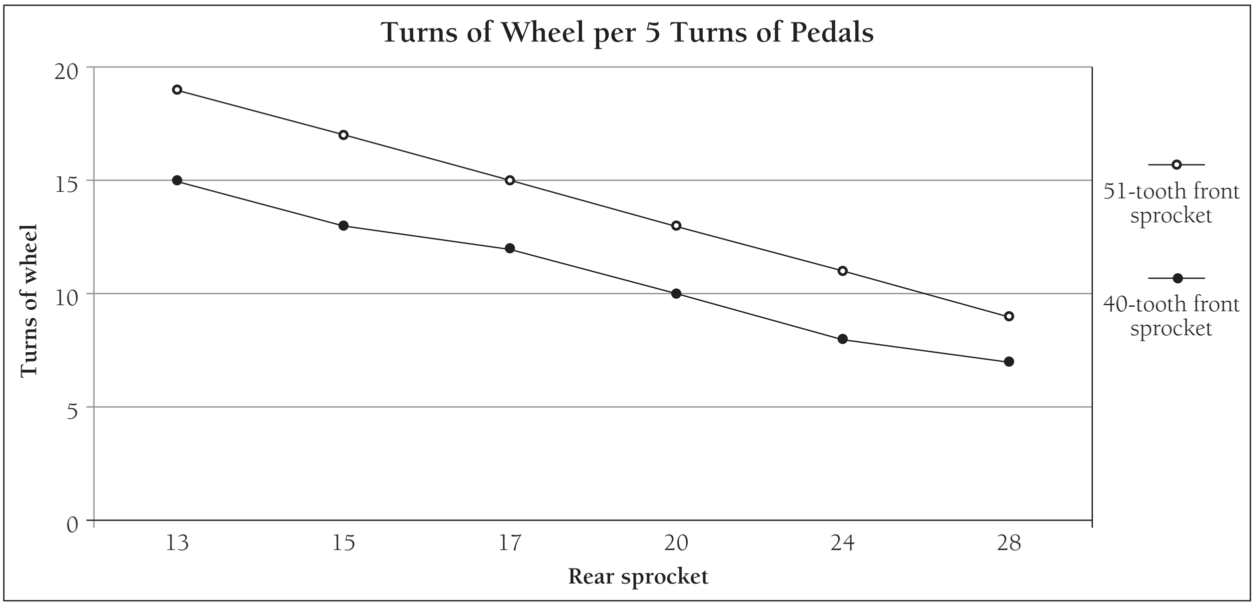
Question **1** is designed to build on the students' prior experience. Many will own or have ridden bikes with gears and will understand the practical benefits of gears. Some will also understand the function of the gearbox in a car, particularly if the family has a car with a manual gearbox. They are likely to know the terms first, second, third … gear and low/high gear.

Question **2** is a practical investigation. It requires students to check out all possible gear combinations on a particular bike. Depending on the bike, there may be between 10 and 27 of these. To succeed with the task, the students will need to be systematic and consistent. They have to count the number of times the rear wheel turns, so they also need to decide what to do with part turns. (Counting to the nearest complete turn is fine.)

The following example is for a bike with 2 sprockets at the front and 6 at the rear.

Turns of Wheel per 5 Turns of Pedals						
Front sprocket (teeth)	**Rear sprocket (teeth)**					
	13	**15**	**17**	**20**	**24**	**28**
51	*19*	*17*	*15*	*13*	*11*	*9*
40	*15*	*13*	*12*	*10*	*8*	*7*

The data in the table can be graphed like this (the connecting lines are not needed but they help make the trends clearer):

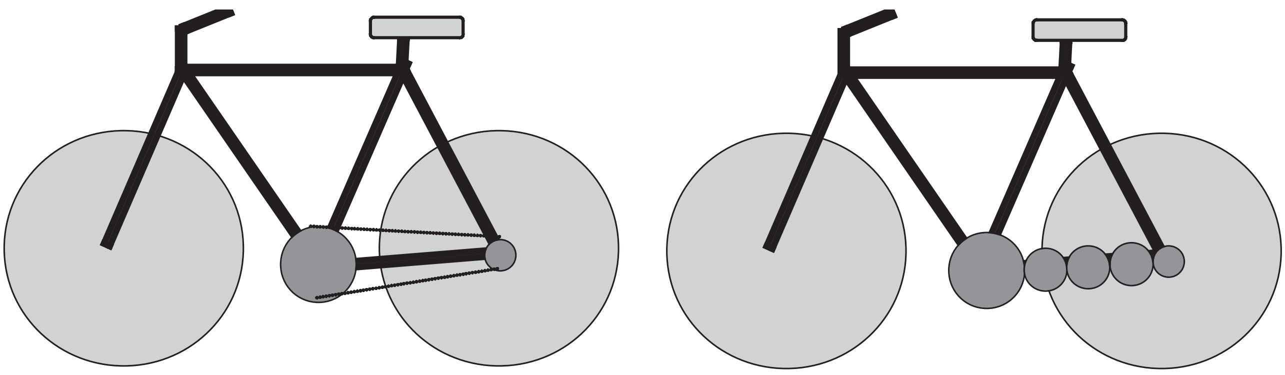


Important note: The horizontal scale is not linear (equal increments). Instead, it represents a typical cluster of gears.

Graphs will vary considerably, depending on the particular bike. But they should enable students to easily identify which gears are higher and which are lower. The above graph makes it clear that, in this example, the two highest gears use the 51-tooth front sprocket and the two lowest use the 40-tooth sprocket. Two of the gears in each series are identical or almost identical (those that turn the wheel 13 and 15 times).

Points of entry: Science

The introductory note on sprockets is an opportunity to discuss **energy** transfer. The chain on the bike allows the pedals and wheel to be spaced far apart without having to put extra gears in the middle. The chain does not change the gear ratio; rather, it transfers energy from the front gear to the rear. The reason we use a chain and sprocket (left-hand diagram) as opposed to cogs is that the chain removes the need for lots of cogs (right-hand diagram). The gear ratios of each bike are the same (the cogs in the middle of the right-hand bike do not affect the ratio).



When you ride a bike, you do the work. Make explicit the idea of "work" in the scientific sense of force x distance. When a rider is pedalling uphill, they are working against gravity as well as against air and road friction. On a 10 metre hill, for example, it doesn't matter which gear is used: the amount of work will be the same. Using a lower gear spreads out the work over a longer time.

Making Better Sense of the Physical World explains the advantage of gears for bikes very clearly:

> When cycling uphill, it helps to have gears. Like levers, gears give a mechanical advantage and make pedalling easier. It is important that students realise that gears give no more power – they just spread the effort over a greater distance, making the wheels turn less for each turn of the pedals. Gears can also operate the other way. When you cycle in high gear along the flat, you are concentrating the effort into a short distance and moving the load further. In this case, the wheel turns more for each turn of the pedals. This means that pedalling takes more effort but the wheels carry you further and faster.
>
> *Making Better Sense of the Physical World*, p. 115

Bikes with 21 and 18 gears usually have the same bottom and top gear, but the 21-gear bike has a greater number of combinations in between, which gives the rider more options when it comes to finding an "ideal" gear in any circumstances. Competitive cyclists can customise the sprocket combinations on their bikes.

Activity Two

Instructions for balancing experiment

i. Balance a 30 cm ruler by placing a thick pencil or a marker pen under it at the 15 cm mark (the fulcrum). Place 1 washer on one end of the ruler at the 30 cm mark. Place 2 washers (identical to the other washer) together on the other side of the fulcrum. Move the 2 washers along the ruler until it balances.

ii. Enter the positions of the washers on the table below. (Measure from the fulcrum.)

iii. Move the single washer to the 25 cm mark on the ruler and then move the other 2 washers until the ruler balances again. Mark these positions on your table.

iv. Repeat for the 20 cm mark on the ruler, and so on.

Distance (cm) from the fulcrum of 1 washer	Distance (cm) from the fulcrum of 2 washers (to balance)
15	
10	
5	

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15	
10	
5	

Copymaster: Swing Time

Activity Two

Number of extra weights	Time taken for 5 swings			
	Trial 1	Trial 2	Trial 3	Average

Activity Three

Fraction of the rope	Time taken for 5 swings		
	Trial 1	Trial 2	Trial 3
1			
0.75			
0.5			
0.25			

Activity Two

Number of extra weights	Time taken for 5 swings			
	Trial 1	Trial 2	Trial 3	Average

Activity Three

Fraction of the rope	Time taken for 5 swings		
	Trial 1	Trial 2	Trial 3
1			
0.75			
0.5			
0.25			

Copymaster: Zoom, Zoom!

Activity One

Mass	Distance travelled (metres)			
	Trial 1	Trial 2	Trial 3	Average
Car + 0 weights				
Car + 1 weight				
Car + 2 weights				
Car + 3 weights				

Activity Two

Height	Distance travelled (metres)			
	Trial 1	Trial 2	Trial 3	Average
1 extra block				
2 extra blocks				
3 extra blocks				

Activity One

Mass	Distance travelled (metres)			
	Trial 1	Trial 2	Trial 3	Average
Car + 0 weights				
Car + 1 weight				
Car + 2 weights				
Car + 3 weights				

Activity Two

Height	Distance travelled (metres)			
	Trial 1	Trial 2	Trial 3	Average
1 extra block				
2 extra blocks				
3 extra blocks				

Copymaster: Gearing Up

Activity One

Game	Number of teeth on the first cog	Number of teeth on the second cog	Number of turns the second cog makes when the first cog is turned once	Number of turns the first cog makes when the second cog is turned once
1				
2				
3				
4				
5				

Turns of Wheel per 5 Turns of Pedals						
Front sprocket (teeth)	Rear sprocket (teeth)					

Activity One

Game	Number of teeth on the first cog	Number of teeth on the second cog	Number of turns the second cog makes when the first cog is turned once	Number of turns the first cog makes when the second cog is turned once
1				
2				
3				
4				
5				

Turns of Wheel per 5 Turns of Pedals						
Front sprocket (teeth)	Rear sprocket (teeth)					