Lesson 5: Measuring Forces

Australian Curriculum: Mathematics — Year 5

ACMNA291: Use efficient mental and written strategies and apply appropriate digital technologies to solve problems.

ACMMG108: Choose appropriate units of measurement for length, area, volume, capacity and mass.

Australian Curriculum: Mathematics — Year 6

ACMNA123: Select and apply efficient mental and written strategies and appropriate digital technologies to solve problems involving all four operations with whole numbers.

ACMMG135: Connect decimal representations to the metric system.

Australian Curriculum: Science — Years 5 & 6

ACSIS090: Construct and use a range of representations, including tables and graphs, to represent and describe observations, patterns or relationships in data using digital technologies as appropriate.

- Identifying patterns in data and developing explanations that fit these patterns.

Lesson abstract

In this lesson students make and calibrate their own forcemeter and use it to measure pushes and pulls. Students discover what happens when two forces pull in opposite directions and draw force diagrams to represent the results.

Mathematical purpose (for students)

To make a measuring instrument, a *forcemeter*, and use it to measure pushes and pulls.

Mathematical purpose (for teachers)

This lesson gives students a more concrete idea of what force is and how to measure it. Students will understand that forces have size and direction, and will get a physical feel for the size of forces between 1 Newton and 5 Newtons. Through experimenting with forces in opposite directions, students develop their understanding that forces can counteract and balance each other. The lesson also develops measurement ideas such as calibration (matching your measuring instrument to a standard) and accuracy.

Lesson Length 90 – 120 minutes approximately (possibly as two lessons)

Vocabulary Encountered

- Forcemeter
- Calibrate
- Newtons

Materials — See Teachers' Guide: Appendix B

- Materials for making forcemeters
- Toy cars, masses, kitchen scales
- Workbook *ST3_Motion_Y5&6_5a_Workbook.pdf* (1 per student)

We value your feedback after these lessons via https://www.surveymonkey.com/r/JJCGHVX

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Background

Force

Students will have a range of ideas about what a force is. The purpose of the introductory discussion should be to all agree that, despite subtle differences, forces can generally be described as pushes or pulls. This will be reinforced when students use their forcemeters to measure pushes and pulls.

- Examples of forces should be connected to students' experiences of pushes and pulls: for example *using too much force* is pushing or pulling too hard, *forcing a door shut* means having to push hard because it is stuck.

- Students may suggest the more everyday usage of the word force, e.g. *I feel like I'm being forced to eat broccoli* or *the armed forces* or *by force of will*. While noting the strong connection between this usage and the idea of pushes and pulls, remind students that words in Science often have a precise, well defined, 'narrow' meaning, and in this case, force means 'a push or a pull'.

The unit of force is Newtons (N), named after the scientist and mathematician, Sir Isaac Newton, who formulated laws explaining how force and motion are linked.

Mass and Weight

Mass is the amount of matter in an object, measured in grams. In everyday life we often call this weight, but in science the word 'weight' is used in a different way: it means 'the amount of force pulling the object down due to gravity'.

- For example, we might say "the bag of apples weighs 1kg", but a scientist would say "the bag of apples has a *mass* of 1kg, and a *weigh*t of about 10 Newtons". (It is closer to 9.8N, but for these lessons we will approximate to 10N.)
- When we pick up an object, we feel the weight of it as the amount of force needed to stop the object falling to the ground.
- The challenge in this lesson is for students to make their own forcemeters, and calibrate and use them to measure pushes and pulls. Calibration is done against the gravitational forces of 1, 2, 3, 4 and 5 Newton produced by masses of 100, 200, 300, 400 and 500 gram.

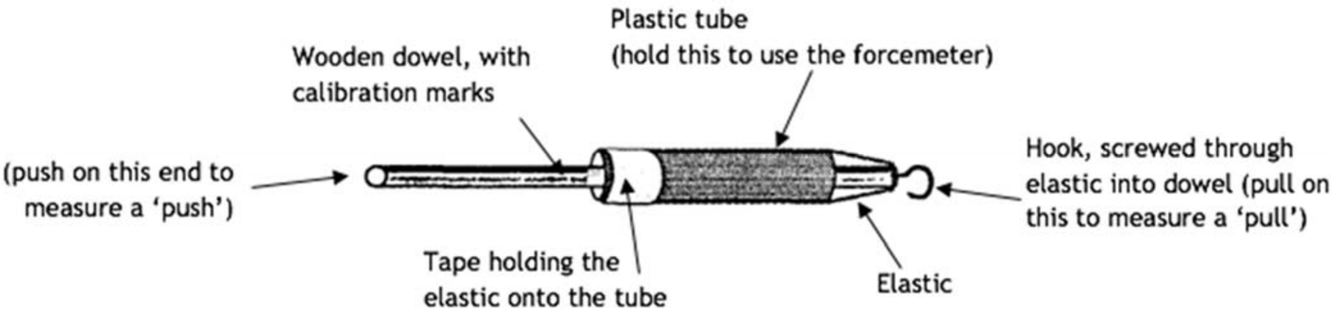
Other Notes on Weight

- The formal relationship between weight and mass is Weight = mass x (acceleration due to gravity).
- On the Earth's surface the acceleration due to gravity is essentially constant (9.8 m/s per second, approximately), which means that your weight is the same everywhere on Earth. On the moon, however, the acceleration due to gravity is much lower (around 1.6 m/s per second). This means that even though you remain the same mass, your weight on the moon is much less.

Force and Acceleration

When force is put on an object, it is understood intuitively that the object tends to move. Students should notice that when they apply unbalanced forces to a stationary object, it will move in the direction of the greater force. The idea that this movement is in fact acceleration is not introduced until next lesson.
The final activity in this lesson is similar to the game 'tug of war': if both sides are pulling with the same force, the whole thing stays stationary. If one side pulls harder, everything accelerates in that direction.
A common misconception dealt with in this lesson is that *if an object is stationary, there are no forces on it*. Students will see that an object can be stationary with equal forces on it in opposite directions cancelling each other out.

The forcemeter



This forcemeter uses the stretchiness of elastic to measure forces. The plastic tube is held while the dowel is either pushed or pulled against the elastic. Calibration marks are added after the forcemeter is constructed, by hanging known masses on the hook and marking on the dowel where the plastic tube sits for each mass.

It comes as a surprise, initially, that the scale produced on the forcemeter is not linear, and this is best explained to students by saying that this is due to the way the elastic behaves.

While the forcemeter is, of course, not perfect, it does give reasonably good results in the range of 1 to 5 Newton. It is important to be aware that the elastic will become permanently deformed if too great a mass is hung on the hook, and this will affect the accuracy.

Calibrating a forcemeter

Once calibrated, students can use the forcemeter to:

- Measure a force e.g. the force needed to close a door, slide a cup, or turn the page of a book.
- Reproduce a force (e.g. 1 Newton) by pushing or pulling until the tube sits at the correct mark. This enables students to 'get a feel' for how strong these forces are.

Lesson Introduction

The challenge for this lesson is 'Making and using a forcemeter to measure pushes and pulls'.

Force and Weight

What is a Force?

- Confirm that a force is a push or pull.
- Explain to students that they are going to make their own device for measuring forces.
    - Show a completed forcemeter to the class.
    - Point out the parts and the calibration marks. Explain that these marks are measuring marks like on a ruler to help people tell each other about the measure of their forces.
    - Show how to use the forcemeter to measure pushes and pulls.
    - Measure a particular push or pull, reading out the force in Newtons. Explain that Newtons are the unit we use for force. A force of 1 Newton is about the same as the weight of a 100g mass.

Weight as a Force

- Ask students what is meant by the *mass* of an object. (Ans: the amount of matter in the object, measured in grams or kilograms)

- Explain to students: Mass is the amount of matter in an object, measured in grams. In everyday life we often call this weight, but in science the word 'weight' is used in a different way: it means 'the amount of force pulling the object down due to gravity'.
    - For example, if we were at the fruit shop we might say "the bag of apples weighs 1kg", but a scientist would say "the bag of apples has a mass of 1kg, and a weight of about 10 Newtons".
    - When we pick up an object, we feel the weight of it as the amount of force needed to stop the object falling down to the ground.
- After we construct out forcemeters, we need to work out where to put the measuring marks. This is called calibration. Ask students how we might do this.
    - Students might draw on the analogy of making their own ruler from a piece of wood. How would they work out where to put the marks? (Ans: match it to another ruler; measure some objects with known lengths.)
    - To calibrate our forcemeter we will use some forces with sizes that we already know. We already know a 100g mass is about 1 Newton. What mass will we need to get 5 Newtons? (500g)

Producing Masses for Calibration (Optional)

This activity is optional and is not included in the student workbook. It involves estimation of mass and can involve decimals if desired. It is best done with regular objects, such as washers or coins. We recommend using collections of 20 cent coins to produce the masses, as 9 of these coins have a mass very close to 100g.

- Explain to students that before making their forcemeters they will need masses of 100, 200, 300, 400 and 500 grams to use in the calibration process.

Estimating 500 g

- Give each group a small resealable plastic bag containing $10 worth of 20 cent pieces & explain that you will be able to tell easily whether they are returning them all at the end of the lesson.
- Ask each group to estimate, by hefting, how many coins are needed for 500 grams. To help them estimate they can try and remember how heavy some everyday objects feel, e.g. 500g butter, half a 1 kg bag of sugar, two 250mL juices.
- When students are satisfied, they should seal their plastic bags and record the number of coins they have used.
- Ask one student from each group to come to the front and find the mass of their bag of coins using the digital kitchen scales. Use a table like the following to record each group's results on the whiteboard.

Group no.	No. of coins	Mass (g)

- Based on the results of their first try, groups should now try to estimate 500 g of coins again. Retest and record their estimates, one group at a time, to see which group comes up with the closest mass.

Class Discussion

- Tell students that we should all agree on how many coins are needed for a mass of 500 g.
- Based on a 20¢ coin having a mass of either 11 g or 11.2 g (depending on the year level and students' familiarity with decimal numbers), ask students to calculate how many coins are needed for 500 g — the answer should be rounded to 45 coins. This will translate neatly to nine 20¢ coins per 100 g.

- When most students have calculated the number of 20¢ coins for 500 g, ask them to calculate the number for 100 g, 200 g, 300 g, and 400 g. Record the results in a table like the one below for reference during this lesson and Lesson 6.

Mass (g)	No. of 20¢ coins
100	
200	
300	
400	
500	

Making Your Own Forcemeter

- Tell students that the instructions for making a forcemeter are in their workbooks.
- Students will need to share the equipment and help one another.
- Ask students to collect the other equipment required [Workbook Step 1].
- Ask students to attach the elastic to their piece of plastic tube.
    - o Check that students have attached the elastic firmly as explained in the workbook and that the elastic is attached to opposite sides of the plastic tube [Workbook Step 2].
- If needed, help students make a small hole in one end of their piece of dowel using the poster pin [Workbook Step 3]. If you are concerned that this will be difficult for students, you could prepare the dowels beforehand by starting to hammer a nail into the end of each piece of dowel — this can be done quite quickly by standing a bundle of 5 or 6 dowels on a table and hammering the nail into each one.
- If needed, help students attach their tubes and elastic to the piece of dowel by screwing the hook into the centre of the length of elastic [Workbook Step 4].

Calibrating Your Forcemeter

- Students need to calibrate their forcemeter, holding it as shown in the picture.
- Ask students to start by hanging a 500 g mass on the hook and drawing a line on the dowel on the forcemeter at the exact point where the top of the tube now reaches. Students should mark this as 5 [Workbook Step 5].
- The easiest way to do this is for all students in a group to pass around the 500 g mass and help one another to hold and mark their forcemeter if needed. They can now remove 100 g from the plastic bag and repeat the process with 400 g [Workbook Step 6].
- Ask students to repeat the process with masses of 300 g, 200 g, 100 g, and no mass. [Workbook Step 7].
- Students now have their own forcemeters to use to measure pushes and pulls.

Using Your Forcemeter

- To get a feel for what the forcemeter is measuring, ask students to work in pairs and test their forcemeters by gently pushing one another with a force of 1 Newton or 2 Newtons.
  Ask students to find some more things to push [Workbook Step 8].
- Ask students to find 3 things that need a force of between 1 and 5 Newtons to push or pull and record their results in the table in their workbooks [Workbook Step 9].

Class Discussion

- Discuss student's items and the forces they used.
- *Were there any unexpected results?* For example:

- o Different forcemeters giving a different measurement for the same object. (Our forcemeters aren't perfect, or maybe we pushed a bit differently.)
- o Unsure how to read the force when it is between marks because the scale marks are not all the same distance apart. (When we estimate between the marks we need to remember that it's going to be an approximation.)

Two Forces Pulling in Opposite Directions

- In this activity students will discover that:
  - An object with forces pulling in opposite directions will move in the direction of the larger force.
  - The greater the difference between the two forces, the faster the car moves.
  - If the two forces are the same, the car does not start moving.
- Tell students that they will experimenting with pulling a car in opposite directions.
- Give each group a toy car or trolley to use. Students will need to hook forcemeters to the front and back of the car.
- Ask students in each group to select a Starter and two Pullers. The remaining students will be the Judges – students will rotate roles later [Workbook Step 10].
- For each turn, the Pullers choose a force from the Force Diagram on the chart. This is the force each Puller uses. The Starter holds the car or trolley steady at the starting point. The Pullers pull steadily with their chosen force, not moving their arms. The Starter lets go. The Judges watch carefully to see which way the car or trolley moves. Each person uses the chart to record the direction in which the car or trolley moves [Workbook Step 11].

Turn	Force diagram	Direction car moved
1	← 2N • 3N →	
2	← 4N • 2N →	
3	← 1N • 5N →	
4	← 3N • 3N →	
5		
6		

- Discuss with the students how to fill in the workbook table (e.g. by agreeing to draw an arrow in the direction of the movement & representing greater distance moved by longer arrows).
- Students devise & carry out experiments 5 & 6 and record their results.
  - Any pair of forces will be useful to test, but encourage students to think of ways to test any hypotheses they may have, e.g. 4N/4N to check if the equal forces give no movement, or checking 5N/1N to see if the car moves similarly to Turn 3 but in the opposite direction.
  - If desired, students can carry out further experiments.
- Each group discusses & writes down their rules for predicting what happens [Workbook Step 12].

Class Discussion (Based on Workbook Answers)

- *What was your group's rule for the way the car or trolley moves?* Ask the following questions to assist discussion:
  - *What happens when you tried to pull with different forces?* [The car or trolley moves in the direction of the greater force.]

- *Did it matter how much bigger one force was than the other?* [A bigger difference results in more motion.]
- *What happens when you managed to pull with equal forces?* [The car or trolley didn't move.]

- Students' rules for how the car or trolley will move typically recognise that it moves in the direction of the greater force and that balanced forces result in no motion, as shown in the examples below.

> The trolley will get pulled towards which ever direction has the most newtons. If the force is balanced it will not move at all and will stay in the same position.

> The trolley will Move the amount of newtons between the two numbers. The trolley always moves towards the bigger number. If the forces are balanced they will stay the same.

Two examples of students' predictions

However not all students recognise that this is what will happen!

> The trolley will stay in it's same place.

Another student's prediction

Student Reflection

- Ask students to write what they have learned about force and how to measure it [Workbook Step 13].

You may wish to discuss this with the class before they write anything and/or ask a few selected students to read their answers afterwards.

An interesting example that recognises the non-linear nature of the calibration scale is reproduced here.

> I found out that newtons do not have an equal gap in between each one unlike grams and centemeters.

The forcemeter scale is not uniform.