re(Solve) MATHS BY INQUIRY

Lesson 6: Force and Motion

Australian Curriculum: Mathematics — Year 5

ACMSP118: Pose questions and collect categorical or numerical data by observation or survey.

ACMSP119: Construct displays, including column graphs, dot plots and tables, appropriate for data type, with and without the use of digital technologies.

Australian Curriculum: Mathematics — Year 6

ACMSP147: Interpret and compare a range of data displays, including side-by-side column graphs for two categorical variables.

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.

- Constructing tables, graphs and other graphic organisers to show trends in data.
- Identifying patterns in data and developing explanations that fit these patterns.

ACSIS218: Compare data with predictions and use as evidence in developing explanations

- Sharing ideas as to whether observations match predictions, and discussing possible reasons for predictions being incorrect.

Lesson abstract

In this lesson students make a streamer graph of the motion of a car or trolley when it is pulled in opposite directions. The forces on the car are provided by masses on strings over pulleys. After discussions about the use of pulleys and forcemeter accuracy, students set up their equipment and predict what will happen. They then create streamer graphs to represent the distances the car or trolley moves each second.

Mathematical purpose (for students)

To investigate the motion of a car which has unbalanced forces on it using a streamer graph.

Mathematical purpose (for teachers)

Building on the previous lesson, where unequal forces acting on a stationary object produced motion, students confirm with streamer graphs that this motion is acceleration. Intuitive ideas about rate of change are developed through a comparison with graphs from Lesson 2. The extension activity investigates whether a larger unbalanced force produces a larger acceleration, developing more complex rate of change ideas. An optional activity increases understanding of instrument accuracy and uses statistics to decide which readings are most reliable.

Lesson Length 90 minutes approximately

Vocabulary Encountered

- Pulley
- Rate of change

Materials — See Teachers' Guide: Appendix B

- Tables, cars, pulleys, masses, string, forcemeters, streamers etc.
- Workbook *ST3_Motion_Y5&6_6a_Workbook.pdf* (1 per student)

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

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Australian Academy of Science

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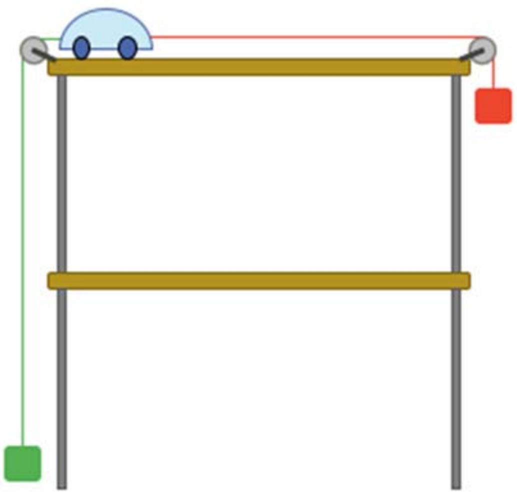
Background

Force and acceleration

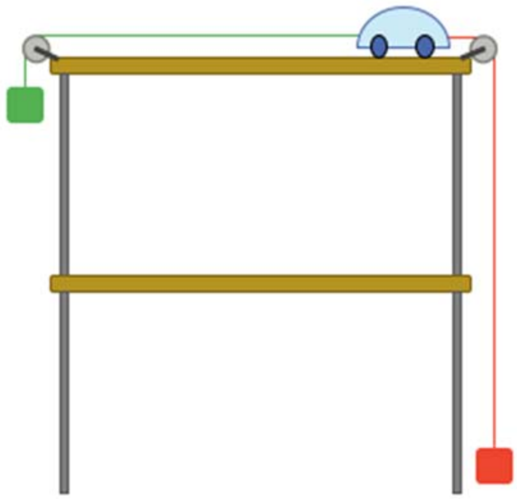
Unbalanced forces result in acceleration in the direction of the greater force.

In lesson 5, forces were applied to the car or trolley by two forcemeters hooked onto it. This allowed students to see the direction of motion, but to investigate further (and discover that the car is accelerating) we need to adjust the set-up and get the forcemeters out of the way of the path of the car.

In this lesson, masses are used to apply unbalanced forces to the car or trolley. This is done by attaching the mass to a string which goes over a pulley and then is tied to the car, as shown below.



Start position, with smaller mass near the ground



End position

Making the experiment work

It is vital to practise with your equipment beforehand, as adjustments may be necessary. To make this set-up work properly, consider the following:

- Masses cannot hit the floor: if the mass hits the floor it will not be pulling on the string any more. The table top must be high enough off the ground for the masses to start and finish off the floor.
- The string and masses should not touch the table: the pulleys need to be positioned so that the mass can fall without bumping into anything.
- The height of the set-up is approximately the same as the length of the table. This is because the mass needs to travel as far down as the car travels across. A longer table can give a better graph with more streamer sections but may need to be raised to an inaccessible or unsafe height.
- To get a graph with 4-5 sections, the car needs to move for 4-5 seconds. This can be achieved by making the car slower (i.e. giving it a smaller acceleration). Options include:
    - Keeping the difference in the two masses small. Students will need to be able to adjust their masses by small amounts to get the desired travel time.
    - Making the car heavier.
    - Increasing friction on the table (must be increased evenly across the surface).

- String cannot be stretchy, or it will get longer when the mass is hung on it.
- The car or trolley needs attachment points at front and back for the string.
- The string should run horizontally from the car to the pulley.
- If your pulleys are cotton reels on coat hanger wire, make sure the wire is attached to the table out of the car's path, e.g. attached under the table.
- For accessibility, attach the pulleys about 10cm from the long edge of the table.

The effect of the pulley

Before experimenting with their cars, students investigate how the pulley affects the force. They hang a mass over one pulley while holding a forcemeter where the car will be, and measure the force.

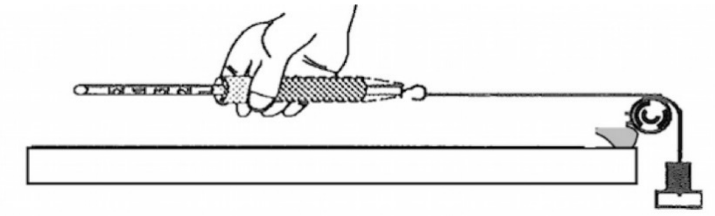
- In an ideal set up, the pulley and string will not change the size of the force, but will mean the force is now horizontal instead of vertical. This can be explained as gravity pulling on the mass, which pulls on the string, which goes around the corner and pulls on the forcemeter. Some students might describe the 'pull on the string' as the tension in the string, but it is not necessary to follow this up.
- Note: a pulley is an example of a simple machine, which can be used for changing the direction of a force. Other simple machines include levers (which change the size of a force) and sets of pulleys (called a *block and tackle:* which can change the size and direction of a force).

Lesson Introduction

The challenge in this lesson is to investigate the motion of a toy car or trolley with unequal forces applied in opposite directions.

- Remind students what happened in the last lesson when the forces were equal. (Equal forces balanced each other, and the car did not start moving.)
- Each group of students will need several forcemeters from Lesson 5. It is not essential for each student to have their own.
- Demonstrate how to attach the pulleys to the tables (giving the masses a clear drop to the floor and keeping everything but the pulley itself out of the path of the car).
- Demonstrate how to put one table on top of the other safely, explaining that this doesn't happen until Workbook Step 6.

Measuring Force over a Pulley



Students investigate how the pulley affects the force. They hang a mass over the pulley while holding a forcemeter where the car will be, and measure the force.

- Tell students that the instructions are in their workbooks.
- Ask students to collect the equipment required for each group [Workbook Step 1].
- Check that students attach the pulleys correctly [Workbook Step 2].
- Check that students remember how to use their forcemeters & attach the correct masses [Workbook Step 3].

Class Discussion

- Ask students if their results matched what they expected to happen [Workbook Step 5].
    - Some students expect the forcemeter reading to be the same as the weight of the mass, i.e. a 400g mass producing a reading of 4 N, which is what should happen.
    - Other students may think that introducing a single pulley results in a smaller force being read.
    - Other students may have not had any clear expectations.
- Confirm that provided the forcemeters have been calibrated accurately and have not been damaged a 400g mass should produce a reading of approximately 4N, meaning that a downward force of 4N has been transformed into a horizontal force of 4N with a pulley.

- If this result is not clear, ask students to measure the same masses *without* the pulley (i.e. with the mass hung from the forcemeter), and see if they get the same result as they did *with* the pulley. In this case even an inaccurate forcemeter will show that the horizontal force is approximately the same as the weight.
- If the class has a large range of readings and/or is concerned about the variation in readings, the optional activity below may be helpful.

- *Can you explain how this happens?*
  - Some students might discuss the weight pulling on the string, which then pulls on the forcemeter.

Optional: Which Forcemeter is the Best?

This activity is an opportunity to discuss accuracy and statistical techniques for deciding what data to use.

A good measuring instrument is one that gives accurate readings (i.e. readings that match the real quantity being measured). It is likely that some forcemeters will have become quite inaccurate due to their elastic having been deformed or some other reason. In this activity, we will all measure the same unknown mass, compare our readings, and discuss any differences.

- Give each group the same unknown mass to measure with their forcemeters (e.g. 200g, or 250g). Each student measures the weight and records it on the whiteboard. Readings might be expressed as 'a bit less than 3N' or 'between 2N and 3N' or with approximate fractions or decimals if students are confident with this.
- *Did different forcemeters give different results? Why do you think this might be?*
  - Incorrect calibration
  - Elastic has 'lost its stretch' from being stretched too much. (If the elastic has been stretched out of shape, the 200g mass will hang further down than before, and the forcemeter will read more force than 2N.)
  - Forcemeter breaking & being rebuilt, but not re-calibrated
  - Human error e.g. reading the mass or the forcemeter.
- *How could we decide which is the best reading, i.e. which reading is closest to the real force?*
  - Find an approximate average of the readings (unlikely to be 'adding them all up and dividing' because of how the readings are expressed).
  - Find the most common reading (mode).
  - Check for any obviously broken forcemeters and remove their readings from the list.
  - Find any 'far out' readings (outliers): we might choose to remove them.
  - Ask: what happens to the average if all the forcemeters are a bit stretched out of shape? [The average reading will be higher than the actual force, so we won't get an accurate answer. This problem will also affect the mode.]
- *How else could we find the force?*
  - Recalibrate a forcemeter then use it to measure the force. (It can be important to check measuring instruments against a standard, especially if the instrument has parts that might get stretched or worn down.)
  - Find the mass and then use the approximation: 100g mass means 1N weight force.

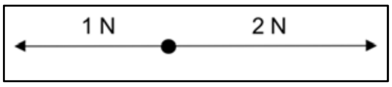
How Does It Move?

Setting up the Equipment

- Help students place the table with the pulleys attached on top of the other table [Workbook Step 6].
- Ask students to cut strings and attach masses and strings to the toy car or trolley as explained in the workbook [Workbook Steps 7 & 8].

  Depending on your own prior experimentation with your equipment, you may need to tell students to change the masses used in this initial experiment.
- Explain the importance of the Starter holding the toy car or trolley steady at one end of the table, facing the anticipated direction of motion.

  Remind students of the force diagrams in Lesson 5 (Workbook 5, Step 11) and ask students to complete the drawing of the forces on the car [Workbook Step 9].



A typical force diagram

The Initial Experiment

- Ask students to predict what will happen when the Starter releases the toy car or trolley [Workbook Step 10.

  Some typical answers are shown here.

Example 1

Same because it's on the Same Thing

Example 2

I think the trolley will start of fast but as the weights come to a stops it will slow down

Example 3

I think it will start at a constan speed and the when it gets closer to the end it will slow down.

Example 4

It will start slow and go faster because the weight is pulling

- If needed, help students with the initial experiment.

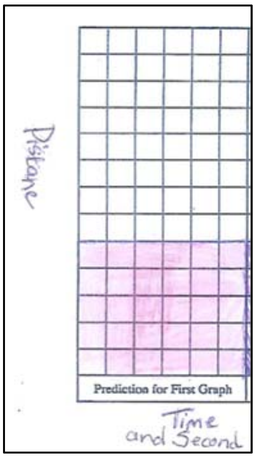
  Encourage students to discuss whether the car or trolley moved as expected [Workbook Step 11].

Creating a Streamer Graph

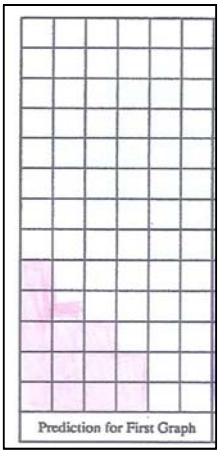
- Explain to students that by constructing a streamer graph for the motion of the car or trolley we will be able to better understand what is happening.
- Set the metronome on for the whole class to use.
- Ask students to experiment with the masses on the ends of the strings to find & record a combination that results in the car or trolley taking 4 or 5 seconds to move the full possible length of the table [Workbook Step 12].
  - Students may need to make fairly small adjustment to the masses, adding or removing individual coins or a few beans at a time.
  - The important factor here is the *difference* in the masses. In trialling, a suitable difference was around 80g, but this will depend on your set-up.
  - It is not necessary for students to measure the masses until they have found a combination that works.
- Students draw a force diagram for the weights they have decided to use. They may need assistance converting the mass in grams into a weight in Newtons. Options include:

- o Hanging the mass on a forcemeter and reading the force (an approximate reading).
  - o Applying the approximate conversion from the previous lesson: 100g means 1N. This can be extended to 10g means 0.1N, and 1g means 0.01N, or weight in Newtons = 0.01 x mass in grams.

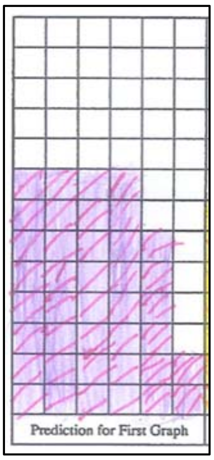
- Ask students to predict what the streamer graph will look like & sketch their prediction in the space provided [Workbook Step 13].
  The graphs below are for the same students as the written predictions above. These students have drawn graphs which correctly reflect their own written predictions.



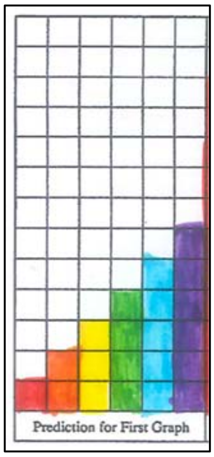
Graph 1



Graph 2



Graph 3



Graph4

- Ask students to release the car or trolley & produce a streamer graph like those in Lessons 1, 2 & 4 [Workbook Step 14].
- Ask groups to fix their streamer graphs onto the pin-board or whiteboard & sketch their Actual Graphs in the space provided [Workbook Step 15].

Class Discussion and Reflection

- Ask students whether their Actual Graphs were similar to any others in this unit [Workbook Step 16].
  - o *Which graph(s) were similar?*
    [Lesson 2: Rolling Downhill — assuming these were reasonably accurate]
  - o *How are they similar?* [Streamer sections increase in length each second.]
  - o *What can we say about the motion of the car or trolley?* [The car or trolley is accelerating.]
  - o Note: if the streamer sections increase by the same length each second, this means that the speed of the car was increasing by the same amount each second. This is constant accleration. In theory a car pulled by a steady force will have constant acceleration, but it is unlikely that the streamer graphs will be accurate enough to show this convincingly.

- Ask students to write what they have learned about the effect of forces on the motion of a car or trolley [Workbook Step 17].
- Explain that one of the processes in science is to generate rules that explain observation and experiments so that these rules can be used to make predictions. Students may also reflect on the mathematical techniques they have used that have enabled them to generate these rules.

  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.

  Some sample responses are shown here.

I learned about mass and Nutons and the trolly moving.

I larn that the force can go anywhere

What happens when you pull a trolly in opposite directions. The trolly goes more to the side that has mor mass.

Some sample responses

Extension Activity

- Ask students to repeat Workbook Steps 12 to 15 using the same smaller mass, but choosing a new larger mass such that the difference between the masses is *double* what it was previously.
- Ask students to compare their first and second Actual Graphs and write down what effect the size of the masses has on the car or trolley's motion.

  Points that might arise in the discussion include the following:

  - The force applied to the car in the second experiment is twice that applied in the first experiment.
  - The total time taken for the car to travel the full length in the second experiment is less than in the first experiment (fewer streamer sections), so it is travelling faster overall.
  - The streamer sections increase in size more quickly than for the first experiment, showing that the car is *speeding up more quickly* or has a *bigger acceleration*.
  - It seems like the larger force applied to the car in the second experiment causes a greater acceleration than in the first experiment.