re(Solve) MATHS BY INQUIRY

MODELLING MOTION

Lesson 4: Rolling Uphill

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 undertake two activities showing deceleration. First, they predict what will happen when a ball rolls uphill, the work in groups to create 'streamer graphs' representing the decreasing distances that the ball rolls each second. Students then investigate how far a ball rolls along a flat track with its surface altered to have more friction (covered in different ribbons), linking increased roughness with more deceleration.

Mathematical purpose (for students)

To see the changes in the distances a ball travels in each second when rolling uphill or along a rough track.

Mathematical purpose (for teachers)

The focus of this lesson is developing an understanding of deceleration — i.e. recognising that deceleration involves continually slowing down (going 'slower and slower', not just 'going slower'). Students learn to interpret the streamer graphs they create, recognising that deceleration is represented in the decreasing length of the strips (i.e. decreasing distance travelled in each second). Class discussion highlights that the ball decelerates because the forces of gravity (pulling down the slope) and of friction work against the direction of motion.

Lesson Length 90 minutes approximately

Vocabulary Encountered

- Deceleration
- Friction
- Modelling

Materials — see Teachers' Guide: Appendix B for full details

- Tracks, launching track, blocks, metronome, ribbons, etc.
- Workbook *ST3_Motion_Y5&6_4a_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

The focus of this activity is deceleration. In the first part of the lesson, a ball rolls uphill and decelerates mainly due to gravity. In the second part of the lesson, a ball rolls on a flat track made ‘bumpy’ using a ribbon and decelerates mainly due to friction.

Rolling uphill

As the ball rolls uphill, most students will correctly predict that the ball will gradually slow down, but many will not be able to describe what this means in terms of the speed of the ball at various points along the track. We have found that moving a finger along the track and asking students to describe the motion of the ball at multiple points helps focus students on the speed of the ball and gives the teacher insight into students' understanding of what is happening. As in Lesson 2, some students believe that they can see a point at which the ball suddenly starts slowing down — a point which they often describe as being where the ball ‘runs out of power’ or ‘loses its force’.

It should be possible to see from the streamer graphs that the ball is decelerating. The ball travels a shorter distance in each second, meaning the lengths of the strips decrease. The deceleration is caused by the force of gravity — gravity acts like a brake to slow the ball down by pulling it down against the upward movement.

Some students will recognise the symmetry between the graphs produced this time and those from Lesson 2, when the ball was rolled downhill.

Getting accurate graphs

In the first activity, students will adjust their equipment so that the ball makes it as far up the track as possible before stopping (or so the ball is moving very slowly when it falls off the end of the track). This is to ensure that the streamer graphs have enough strips.

After the ball stops, it will begin to move back down the slope, accelerating. While it is important for students to observe this (it is needed for Lesson 7), the movement we graph in this lesson is just the uphill section. Including any of the downhill section in the graphs will affect the accuracy.

Matching the start of the uphill motion with a metronome tick is very difficult, since the ball is released from a launching track. Students will need to practise releasing the ball so that it gets to the bottom of the track on (or near) a metronome tick and will need to reject any experiments where this has obviously not occurred.

The Purple streamer should be laid out with one end at the bottom of the uphill track.

Friction

Friction is a force. When two surfaces touch and try to slide over each other, friction tries to stop them sliding. It happens because of how the surfaces interact on a microscopic level. In general, if the surfaces are rougher, the friction is greater. Friction pushes against the direction of motion, causing deceleration.

Everyday examples of friction include:

- Walking: if our feet and the floor didn’t have any friction between them, we would slip over as if on ice.
- Riding a bike: friction between the wheel and the road stops the wheel from slipping and gives you something to ‘push against’ so you can move forward.
- Sliding an object on a flat surface: friction ‘resists’ the motion, making the object slow down gradually (decelerate) and eventually stop.
- Rolling a ball on a flat surface: friction causes the ball to slow down gradually (decelerate) and eventually stop. Note: although it is not part of these lessons, friction also enables the ball to roll instead of slide.

Some other things about friction:

- If a ball rolling to the right decelerates and stops due to friction (like in lesson 4), it will stay stopped, i.e. friction will not cause it to start moving back to the left.
- Although it is not discussed in much depth in these lessons, friction is a very complicated topic. There are several different types of friction and many factors that affect how much friction there is between two surfaces.

Rolling on a flat track

In this second activity, students measure the distance travelled by a ball launched onto a flat track. They repeat the experiment with a variety of track surfaces (ribbons) to see the effect of friction on the distance travelled before the ball stops. Through discussion, they make connections between a shorter distance and greater deceleration.

Experiment with the ribbons beforehand to ensure that the ball stops before the end of the track. The launch height may need to be reduced.

Some students think that the ball stops because it 'runs out of energy' (which is true), but do not think about what forces are involved. The purpose of this activity is to raise students' awareness of friction as a force that acts against the direction of motion, to make it 'visible' by watching and measuring its effect, and to suggest that friction is variable, with its force depending on the surfaces that are touching. A lot to ask of one short activity – but students have experiences of friction on which they can draw.

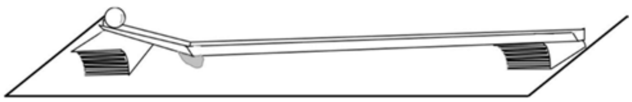
Students often suggest that bumps or 'furryness' are the cause of the slowing down (because they impede the ball's movement) and this is a pretty good explanation! The ball's energy is indeed used up by rubbing the surface to be just a tiny bit smoother.

Rolling a Ball Up a Sloping Track

The challenge for this first activity is 'What happens to the speed of a ball when it rolls uphill?'

Setting up the Track (Groups of 6)

- Students will be working in groups, using a metronome to create their own Purple streamer graphs to investigate what happens to the speed of a ball when it rolls uphill.
- Help students follow the instructions to set up the tracks as shown [Workbook Step 1]. (This is similar to Lesson 2. Students may wish to consult their Lesson 2 workbooks for further instructions.)
- Check tracks as each group finishes, making sure that:



  - o The launching track is joined to the long uphill track as near to the end as possible (in order to make the uphill section as long as possible).
  - o The high end of the launching track is slightly higher than the high end of the uphill track to give the ball enough speed to make it all the way to the end of the track. Later in the activity students will be making fine adjustments to the heights to optimise the motion.

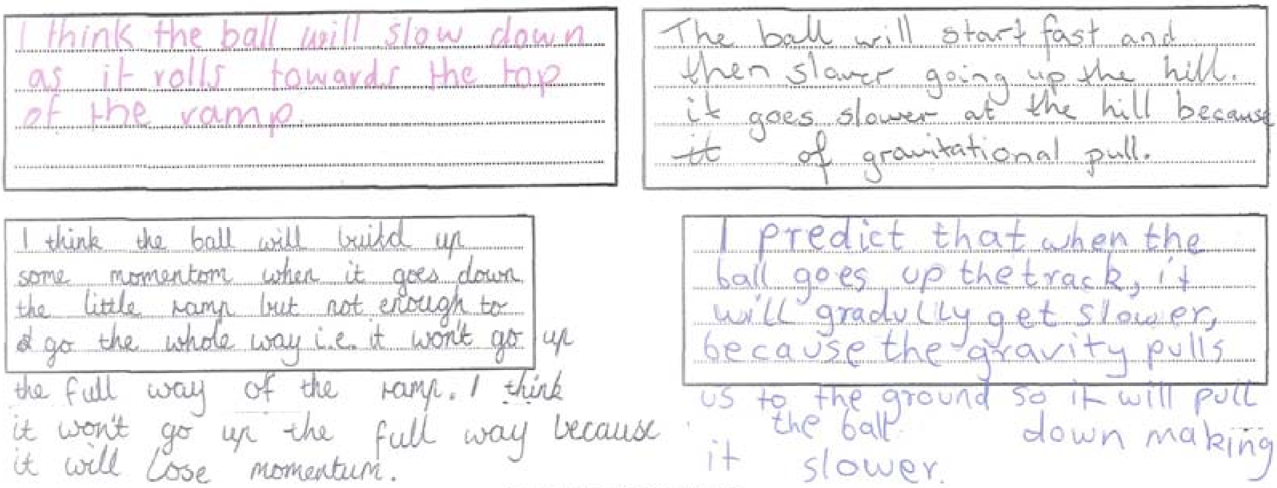
Predicting What Will Happen

- Ask students to predict what will happen when the ball rolls uphill and write or draw their predictions [Workbook Steps 2 & 3].
- Ask students to discuss their predictions in their groups [Workbook Step 4].
- Some sample predictions are shown below.
- Each group of students choose one member of their group to launch the ball from the top of the launching track. They watch what happens when the ball rolls uphill & discuss whether this was what they expected to happen [Workbook Steps 5 & 6].
- Explain to students that while it is interesting to observe that the ball stops and then rolls back down the slope, for this experiment we will be focussing on the uphill motion only.
- Ask students to experiment with different heights for the tracks so that:

Students watching what happens when the ball rolls uphill

- The ball stops just before the top of the track. (This usually needs the launching track to be just a little higher than the uphill track.)
- The ball moves slowly enough on the uphill track to get at least 4-5 seconds of travel. (This will need the slope of the uphill track to be quite shallow.) [Workbook Step 7].

- Students draw their (possibly revised) predictions for the Purple streamer graph [Workbook Step 8].



Some sample predictions

Collecting the data & creating the purple streamer graphs

- Set the metronome on for the whole class to use.
- Explain that ideally the ball should reach the bottom of the launching track (and therefore start its uphill motion) on a click of the metronome, so that the first streamer section is one full second.
  - As it is quite difficult to do this, students may need to run the experiment a number of times before they get decent data.
  - The Launcher can be responsible for deciding if the launch was good enough.
  - Another option, if your track is long enough, is to discard the first second. This will mean fewer columns in your graph.

Students creating the Purple Streamer Graph

- Remind students that they should try to not include any downhill motion.
- The Launcher releases the ball and the Markers put down their blocks when it is their turn [Workbook Steps 9 & 10].
  - Groups should repeat this until consensus is reached that marks are worth recording.
- When consensus is reached, students should lay out the Purple streamer on the table starting at the bottom of the uphill section of the track and create the Purple streamer graph like they did in Lesson 2 [Workbook Steps 11 & 12].
- Ask students to sketch their group's Actual Purple Graph in their workbooks [Workbook Step 13].
- Ask groups to fix their Purple streamer graphs on the board [Workbook Step 14].

Class discussion of displayed purple streamer graphs

- *What do you think happens to the speed of the ball as it rolls uphill?* [Workbook Step 14].
  - Some students will say it 'goes slower'.
  - Other students may say it is 'going slower and slower'.

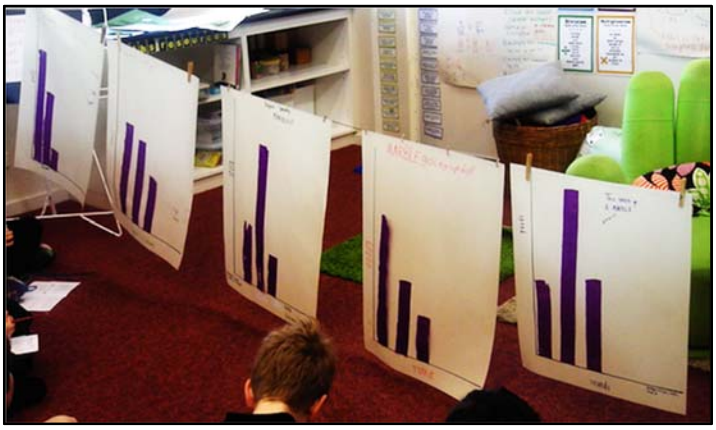
- Encourage consensus that the ball is 'going slower and slower'. Remind students that a shorter streamer means a slower speed for that second, so if the streamers get shorter and shorter that means the ball was going slower and slower.

- After consensus is reached that the ball goes 'slower and slower', introduce the words 'decelerate' and 'deceleration'.
- (Optional) Why does the ball move like this? (see the Teachers' Guide or Background for explanations)
  - Some students may say it is the 'upward slope' that causes the ball to decelerate. Encourage them to think about why this might be the case. (Students may just relate 'slowing down' with 'upward slope', but without considering why it is happening.)
  - Some students may say gravity causes the ball to decelerate. Ask them to describe how gravity behaves in this situation. [Gravity is a force pulling the ball downward and so it acts like a 'brake' (pulling in the opposite direction to the motion of the ball) and slows the ball down.]

- *Is this what you expected the graphs to look like?*
  - *Which of our purple graphs best shows the ball decelerating? Why would you choose this one?*

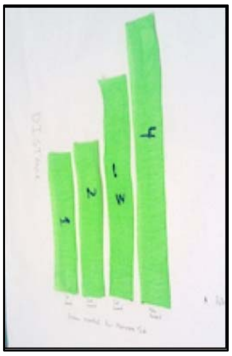
    [Shorter strips represent the ball going slower, so we expect the streamer lengths to decrease with time.]
  - *Why do you think different groups' graphs look different? What could have affected the graphs?*

    Possible reasons include:
    - Difficulty placing blocks accurately.
    - Pasting streamers in reverse (or other incorrect) order.
    - First streamer shorter because the first tick of the metronome happened before the start of the uphill motion.
    - First streamer section much longer because the streamer was lined up with the start of the launching track instead of the start of the uphill track.



A typical collection of Purple graphs

- Draw students' attention to Lesson 2's Green graphs which should still be displayed.
  - *What similarities and differences do you notice about our 'best' Purple graph and our 'best' Green graph from Lesson 2?*
    - Some students will recognise the 'symmetry' between the graphs — in the case of the ball rolling downhill (Lesson 2) the strips get longer and longer, while in the case of the ball rolling uphill the strips get shorter and shorter.
  - *What can we say about how the force of gravity affects balls on a slope?*
    - Gravity always pulls an object downwards, so in the case of the ball rolling downhill it makes it go faster and faster, while in the case of the ball rolling uphill gravity makes it go slower and slower.
  - Ask students if they can now explain why the ball rolled uphill, then stopped, then rolled downhill again. (Students should connect the uphill deceleration and the downhill acceleration with the same force, gravity. This idea is important for Lesson 7.)

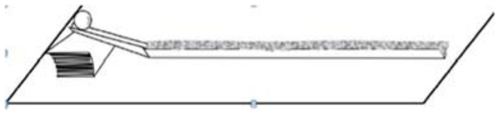


A Green graph from Lesson 2

Rolling on a Flat Track

In this activity students measure the distance travelled by a ball launched onto a flat track. They repeat the experiment with a variety of track surfaces (ribbons) to see the effect of friction on the distance travelled before the ball stops. Through discussion, they make connections between a shorter distance and greater deceleration.

Setting up and Predicting



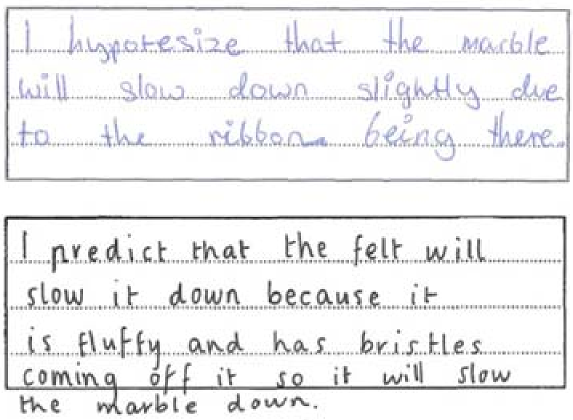
- Help students change their tracks so that the long piece of track lies flat on the table as shown [Workbook Step 15]. (Note: the launch height may need to be reduced so that the ribbons stop the ball before the end of the track. Experiment beforehand to check.)
- Ask students to predict what will happen when the ball is released from the top of the launching track and write or draw their predictions [Workbook Step 16]. (NOTE: no ribbons on the track yet!)

  Ask students to compare their predictions with the rest of their group [Workbook Step 17].

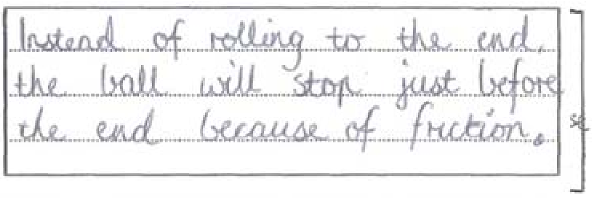
  [Typical predictions include: 'The ball will roll off the end of the track'; 'The ball will go faster and faster'; 'The ball will slow down gradually'; 'The ball will stop before it gets to the end of the track'; and 'If the track went on forever, the ball would continue rolling forever'.]
- Ask students to release the ball and measure and record how far the ball travels [Workbook Step 18].
- Discuss predictions and observations with the class.
  - o What was your prediction, and why? Did what you observed match your prediction?
  - o In fact, in almost all cases the ball will roll off the end of the table.
  - o This experiment is included to show that in the later rolls, when ribbon is used to cover the track, the distance travelled is less.

Covering the Flat Track with Ribbon

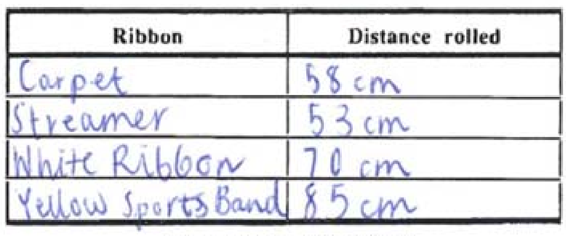
- Give each group a set of two or three different types of ribbon, about the length of the track.
- Ask students to feel the ribbon and write down their predictions of what will happen when the ball is launched onto the flat track after it has been covered with one of the ribbons [Workbook Step 19].


I hypotesize that the marble will slow down slightly due to the ribbon being there.

I predict that the felt will slow it down because it is fluffy and has bristles coming off it so it will slow the marble down.


Instead of rolling to the end the ball will stop just before the end because of friction.

Three sample predictions



Ribbon	Distance rolled
Carpet	58 cm
Streamer	53 cm
White Ribbon	70 cm
Yellow Sports Band	85 cm

A sample completed table

- Ask students record their result from Step 18 in the first line of the table and then use each ribbon in turn to cover the track and roll, measure, and use the table to record the distance travelled for each ribbon [Workbook Step 20]. Remind students to release the ball, without any pushing, from the top of the track each time (or from the same height each time, if they have reduced the launch height).

- Ask students to record the ribbon that gave the shortest distance [Workbook Step 21] and write an explanation of what they think is happening to the speed of the ball and how they think the ribbon makes this happen. [Workbook Step 22].
- Some sample responses to Steps 19,20 & 22 are shown below. In this trial, students used a variety of materials (not just ribbon) to create friction.

If you roll a marble on carpet it goes slower and stops compared to a flat surface, such as a table, concrete, etc...

The ribbon slows the ball down by gripping the ball down, creating friction.

Two sample explanations

Class discussion

- *Did everyone expect the ball to travel a shorter distance with the ribbons on the track? Why or why not?*
- *What do you think was happening to the speed of the ball?* [We think it was getting slower and slower gradually until it stopped, i.e. decelerating. If we made a streamer graph we might be able to find out more about this.]
- *Which ribbon resulted in the shortest distance?*
    - *What do you think a shorter distance says about the size of the deceleration?* [It must have been slowing down faster, meaning a bigger deceleration. (Students should be able to understand that different ribbons slow the ball at different rates, just like a steeper slope slows an upwards travelling ball faster.)]
- *How do you think the ribbon makes the ball slow down?*
    - Some students will say it is the bumpiness of the ribbon that gets in the way of the rolling. Highlight the idea of force, e.g. something 'getting in the way' is like a force pushing back on the ball.
    - Optional: remind students that where there is a deceleration there must be a force causing it.
- Explain that friction is a force that exists between two surfaces that are touching and trying to move past each other. It happens because of the 'roughness' of the surfaces. Friction pushes back to resist the motion.
    - If there was no friction, everything would be slippery like walking on ice or a bike skidding on gravel. Sometimes friction helps us, and sometimes it makes things more difficult: e.g. has anyone ever tried to slide down a rope?
- Ask students to think of some examples of friction from their experiences in everyday life. You could also discuss how friction helps and/or hinders in each example.
- *Can you think of an important difference between how friction acts and how gravity acts?*
    - Friction pushes against the motion, while gravity always pulls down.
        - If an object is moving to the left, friction pushes back to the right. If the object is moving to the right, friction pushes back to the left.
        - Gravity always pulls down, no matter which direction an object is moving, or whether it is moving at all. If a ball is moving up, gravity pulls it down (against the motion). If a ball is moving down, gravity pulls it down (in the same direction as the motion).
    - Friction can only stop something, it cannot get something started. Gravity can start a motion.

Reviewing the First Four Lessons

- Draw students' attention to the graphs from the first four lessons. *How can we see the motion of the ball from the graphs?*
    - Compare the displays of the streamer graphs from Lessons 1, 2 & 4 to see how they (roughly) represent constant, accelerating and decelerating motion, respectively.
- What is modelling? (This unit of work is called Modelling Motion, but what does this mean?)
    - A model is a simplified representation of some aspect of the real world that helps us to understand how something works or help us to predict what might happen. We have been using streamer graphs to model the motion of balls.
    - You might want to show the first two minutes (or the whole 3:36 minutes) of the YouTube video from the European Food Safety Authority: *What is a model* https://www.youtube.com/watch?v=uWuNfhDvZz8
    - Where in the last four lessons did we use a mathematical model to predict what might happen?

      [In Lesson 3 when we predicted the height from which we needed to drop the ball for it to take 2 seconds to hit the ground.]

Student Reflection

- Ask students to write what they have learned so far in this unit, including one thing about using graphs to model motion [Workbook Step 23].
    - You may wish to discuss this with the class before they write anything, reminding students what each of the lessons was about, and ask a few selected students to read their answers afterwards.

Planning a Project

- You may wish to use some time at the end of this lesson to discuss topics for possible projects for students to complete at the end of the unit of work – some suggestions are given in *ST3_Motion_Projects.pdf*