Lesson 2: Rolling Downhill

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 discover what happens to the speed of a ball when it rolls downhill. Students predict what will happen and discuss their predictions, before working in groups to create 'streamer graphs' using paper streamers to represent the distances the ball rolls each second. They interpret what the graphs say about the ball's movement.

Mathematical purpose (for students)

To see how the speed of a ball changes as it rolls downhill.

Mathematical purpose (for teachers)

The focus of this lesson is developing an understanding of acceleration — i.e. recognizing that acceleration involves 'speeding up' (going 'faster and faster') not just 'going faster' (having greater constant speed). Students need to be able to interpret the streamer graphs they create to model the speed of the ball as it rolls downhill, recognising that the increasing length of the strips (i.e. distance travelled per second) represents acceleration. Class discussion can also include explanations of what causes the ball to accelerate (gravity).

Lesson Length 90 minutes approximately

Vocabulary Encountered

- Acceleration

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

- Track, blocks, streamer graph materials, metronome etc.
- Workbook *ST3_Motion_Y5&6_2a_Workbook.pdf* (1 per student)

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Background

Galileo's Ramp Experiments

As discussed in more detail in the Teachers' Guide, several of the lessons in this unit are based on Galileo's experiments on the motion of objects. He used mathematics to prove his theory that an object in free fall experiences constant acceleration which is not related to the mass of the object. This theory contrasted with Aristotle's theory, which stated that objects fall at speeds proportional to their mass (i.e. he thought that a heavier object would fall faster). To measure the motion of a falling object Galileo had to measure both distance and time. He could not measure time very accurately (he relied on a water-clock or a musician beating strict time), so he needed to slow down the motion. Galileo did this by using inclined planes (ramps) for his 'falling ball' experiments. This slowed the motion of the ball so that the time taken could be measured more accurately.

In this (and future) lessons we will use Galileo's brilliant idea to slow down the motion so that we can better observe the speed and acceleration. The equipment needs to be set up in such a way that objects (balls and toy cars or trolleys) travel slowly enough for students to accurately place markers in response to the metronome ticks. The slower pace also gives more streamer sections for the graph. So, for example, in this lesson the angle of the track needs to be as shallow as possible while still allowing the ball to move freely. For this reason, it is important to experiment with your track and marble beforehand, so you have a good idea of what angles will give good results.

Acceleration

The focus of this lesson is acceleration. Acceleration occurs whenever there is a change in the motion of an object. This can be speeding up, slowing down (deceleration, or negative acceleration: in Lesson 4), or just changing the direction of the motion (not dealt with in these lessons).

The particular type of acceleration we will be investigating in this activity is 'speeding up'. The ball starts at rest (i.e. with zero speed) and speeds up gradually as it rolls down the track (providing the track is steep enough and smooth). In each subsequent second, the ball travels further than in the previous second.

Not all students will correctly predict that the ball will keep getting 'faster and faster' — for example, some students believe that 'the ball cannot go fast enough to use up all its speed' and so reaches a maximum speed.

When they watch the ball rolling downhill, many students do not see it 'going faster and faster'. Some believe that the ball starts off slowly (it is not always clear what they mean by this — i.e. whether or not they believe it suddenly starts with some particular speed), continues to move at the same slow speed until some point about a third or half-way along the track, and then suddenly begins to 'gather speed'. We have found it quite uncanny that when a student points out to the others 'the point' at which they believe the ball begins to speed up, everyone (including some of us sometimes!) can suddenly 'see' the spot where this supposedly happens.

It is important to try to establish whether the students believe that the ball just 'rolls faster' or actually accelerates — i.e. 'goes faster and faster'. One of the difficulties here is the lack of a common vocabulary — e.g. the use of the term 'acceleration'. This needs to be established for use in future discussions.

Because the ball travels further in each second, the lengths of the strips on the streamer graph increase. Students should recall from Lesson 1 that longer strips correspond to faster motion. So, it is possible to see from the graphs that the ball is accelerating.

In theory, the acceleration in this lesson is constant, meaning that the speed increases by the same amount each second (and the strips on the graph increase by the same amount each second.) In this experiment it is difficult to get results that show this clearly, mostly due to (unavoidable) measurement error.

Gravity

Gravity is what we call the pull of the Earth on objects near it. Gravity is described as a force, pulling towards the centre of the Earth. We experience gravity as *weight,* e.g. it is gravity that makes it an effort to hold up a bowling ball. Some other ideas to use:

- Gravity is about objects being pulled *towards each other*. Each object pulls on the other.
- Because very heavy objects accelerate very slowly, it looks as if very heavy objects stay still but pull other objects towards them.

- Mostly when we talk about gravity we mean the pull of the Earth (which is very heavy) on all the objects near it. The Earth pulls every single object and person on Earth, as well as all the objects in the atmosphere, the air, and even the moon.

At this age, students have some interesting views on the nature of gravity. Many students think in terms of ‘air pressure pushing things down’, while others have what appears to us quite bizarre views, such as gravity residing in the surface of the earth and then wondering ‘where the gravity goes when we dig a hole in the ground’. Many students think that gravity is meant to be (pretty much) constant, but others believe that it is stronger or weaker nearer the ground.

[The aspect of gravity that is constant on the Earth’s surface is the *acceleration due to gravity*. This is what Galileo’s experiments on falling balls were about: different masses still have the same acceleration. The *force* of gravity in fact pulls heavier objects more, but it results in the same acceleration. This will be discussed briefly in later lessons]

Gravity and Acceleration

Whenever there is acceleration a force must be present. This is a law of physics. The biggest force acting in this case is the force of gravity, and this is the force that will be discussed in this lesson. There is also friction and air resistance that push back on the moving ball, and the force of the track pushing against the ball, ‘holding it up’ or ‘taking some of its weight’. This force (called the *normal force*) will not be discussed in these lessons, but it may help you to give a basic explanation of why a ball accelerates more on a steeper track: the steeper track is not holding the ball up as much. See the Teachers’ Guide for more information.

Rolling a Ball Down a Sloping Track

Practising the experiment beforehand is necessary to give you an idea of what track angles will give good results. Aim for a very shallow angle where the ball rolls for 4-6 seconds. The number of strips in the graph is determined by how many seconds the ball rolls, i.e. for a graph with 4 strips you need a bit more than 4 seconds.

The challenge for this lesson is ‘What happens to the speed of a ball when it rolls downhill?’

Predicting What Will Happen

- Show students a completed sloping track set-up and ask them to predict what will happen when the ball is released from the top of the track [Workbook Step 1].
- Students write predictions in their workbooks [Workbook Step 2].
- Students share their predictions [Workbook Step 3]. Some examples of are shown below:

it will continuely roll down the slope at a constent speed. And it will stay at a constant speed most the way, and possibly get slower, because I've seen something similar done before on a hill.

on our ~~the~~ track it will be slow at the start but will speed up as it goes down because of gravity and because ~~of~~ the land ~~it~~ it's on is diagonally like when your riding a bike down a hill

I predict that once the ball gets to the middle it will start slowing down and be the slowest at the start

it will start off slower then the gravity will then pull it causing it to go faster

The gravity will be bringing it down so it will go faster and faster when the marble is going down.

I think that it will be fast for the start and slow down right at the end of the experiment?

Some student predictions

- Select a student to be the Launcher and ask them to release the ball from the top of the track while the rest of the class watch [Workbook Step 4].
- Class discussion [Workbook Step 5]. *What happened? Is this what you expected to happen?*
  - Consensus is not necessary at this point. Disagreements provide focus for the coming experiment.

Setting up the Track (Groups of 6)

- Tell students that they will be working in groups, using a metronome to create their own Green streamer graphs, similar to the Red and Blue graphs they created in Lesson 1.
- Help students follow the instructions to set up the tracks [Workbook Steps 6, 7 & 8].
- Check tracks as each group finishes to make sure the track is reasonably straight, not sagging in the middle, and that the angle of slope is optimal (i.e. the ball rolls for at least 4 seconds) [Workbook Step 9].
- Ask students to sketch their predictions for the Green streamer graph [Workbook Step 10].
  - Check that they have done this before they start collecting data.

Collecting the Data

- Ask each group to choose someone to be the Launcher [Workbook Step 11].
- The rest of the students in each group are the Markers [Workbook Step 12].
  - It is easier to keep the streamer out of the way until after the marks have been put beside the track.
  - Markers line up beside the track with one small block each. It is best for students to line up on both sides of the track so that they have more space.
  - Everyone needs to know their place in the line — ask students to count down their position saying 1, 2, 3, …

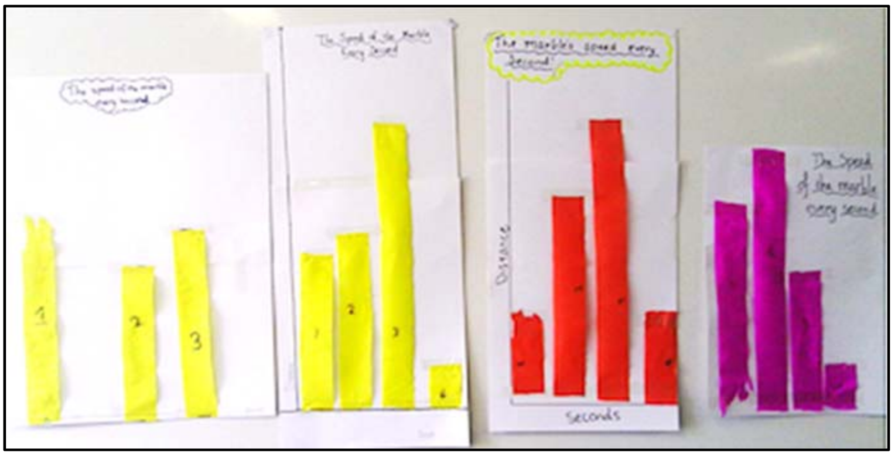
Students getting ready to mark the position of the ball at one second intervals

- Set the metronome on for the whole class to use.
  - Students should work quietly so the metronome can be heard.
  - Experience shows that it is best to have just one metronome in the class as otherwise students get confused as to which one they are listening to.
- The Launcher says ‘Ready! Set! Go!’ in time with metronome and releases the ball from the top of the track [Workbook Step 13].
  - The Launcher should launch the ball by placing a finger lightly on top of the ball, then lifting the finger on ‘Go!’.
- The Markers put down their blocks *on the table* when it is their turn [Workbook Step 14].
  - Since the track is elevated Markers must place their blocks on the table directly in line with the position of the ball. Note: although this measures the horizontal distance not the distance along the track, it is better than the track being knocked when Markers place blocks on the track.
- Groups should repeat the activity until consensus is reached that the marks are worth recording.
- When consensus is reached, students should lay out the Green streamer on the table next to the track and mark the position of the blocks on the streamer [Workbook Step 15].

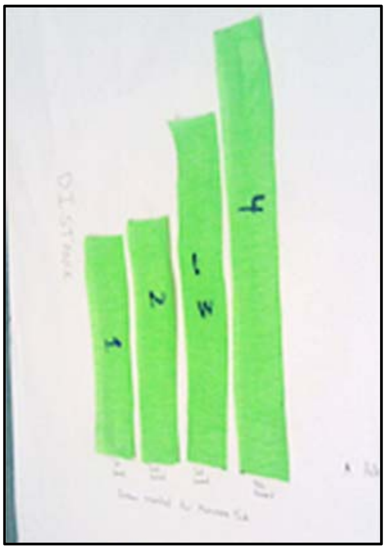
Creating the Green Streamer Graphs

- Ask groups to number the strips 1, 2, 3, … in order before cutting the streamer [Workbook Step 16]. Remind students to discard the last strip if it was not close to a full second.

- When the groups are ready, distribute butcher's paper, glue-sticks, rulers, scissors, etc and ask groups to make their Green streamer graphs [Workbook Steps 17 & 18]. Students should:
    - Mark a horizontal 'base line' near the bottom of the butcher's paper.
    - Line up the bottom of the streamers with the base line.
    - Start with strip 1 at the left.
    - Add a title and label the axes.
- Ask students to sketch their group's Actual Green Graph in their workbooks [Workbook Step 19].
- Ask groups to pin or Blu Tack their Green streamer graphs onto the pin-board or whiteboard [Workbook Step 20].



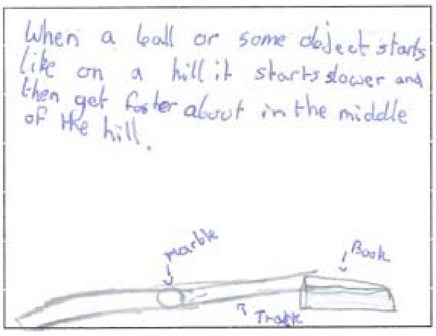
A typical collection of 'Green' graphs. The fourth strip should have been discarded.



A Green Graph based on unusually 'good' data

Class Discussion

- What do you think happens to the speed of the ball as it rolls downhill? [Workbook Step 21].
    - Some students may suggest that the ball starts off slowly and continues to move at a constant speed until a point about half-way where it suddenly speeds up, as can be seen in the example shown here.
    - Some students will just say it 'goes faster'.
    - Other students may say it is 'going faster and faster'.
    - Encourage consensus that the ball is 'going faster and faster'. Remind students that a longer streamer means a faster speed for that second, so if the streamers get longer and longer that means the ball was going faster and faster.



One student's view

- After consensus is reached that the ball does in fact go 'faster and faster', introduce the words 'accelerate' and 'acceleration'.
- (Optional) Why does the ball move like this? (see Background for explanations)
    - Some students may say it is the 'slope' that causes the ball to accelerate. Encourage them to think about why this might be the case. (Students may be used to seeing objects speed up on a slope, and will relate 'speeding up' with 'slope', but without considering why it is happening.)
    - Some students may say it is gravity that causes the ball to accelerate. Ask them to describe what gravity is or how gravity behaves.
    - Students are likely to find it difficult to clearly articulate their reasons. Some sample student answers are below, with some additional information in brackets:
        - 'Because it starts off a bit higher than the table the gravitational pull will make it go faster and faster'. [Gravity 'wants' to pull the ball towards the centre of the earth, but the track

is holding the ball up so that it can only move down along the track, so the ball accelerates in that direction, but not as fast as if you just dropped the ball straight down].

    - ‘Gravity is like the thing that pulls you down to the earth and helps you stay there’. [Gravity is about objects being pulled towards each other OR Gravity looks like very heavy objects pulling other objects towards them. Mostly when we talk about gravity we mean the pull of the Earth (which is very heavy) on all the objects near it, which means every single object and person on Earth.]
  - (Optional) Whenever there is acceleration, there must be a force causing it (a paraphrase of Isaac Newton’s First Law). In this case the (main) force acting is gravity.

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

    [Longer strips represent the ball going faster, so we expect the streamer lengths to increase 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 (or longer) because it wasn’t measuring distance from the start of the track or the first click of the metronome.
    - Last streamer shorter because the ball reached the end of the track a bit before the next tick.
- Ask students to sketch what they think a graph showing acceleration should look like [Workbook Step 22].

Student Reflection

- Ask students to write what they have learned by doing this activity [Workbook Step 23].
  - 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.
  - Highlight or review key points as required.
  - Some sample responses are shown here. In the first response, the student believes that a steeper slope will give a slower downhill speed. A misconception like this (that can be investigated easily using two tracks with very different slopes) is best dealt with immediately, during class discussion.

- If you have higher books it gets slower, less books = faster.
- If you don't mark perfectly it ends up not constent.
- It gets faster most of the time.
- The marble keeps excelerating.
- Everybodys graph is different, depending on their, marble, slope, height + markers.

What I found out in this lesson is that you can use a colum graph to Mesure how fast a ball rolls down a slope.

that depending on what angle the track is the speed is differenc and that the Seths Walking Graph is compleetly differenc

Some sample responses

Extension Activity — Class Discussion

- What would happen to the speed of the ball if we had a much longer track?
    - Some students think it will keep accelerating, getting faster and faster without a limit. (This is a sensible answer, given what students have learned in this lesson.)
    - Others might think it will eventually stop. Ask: *Why? What makes it stop?* (Students may be answering based on everyday experience of friction, for example sliding down a "slip and slide" and stopping on the grass at the end. Friction will be discussed in Lesson 4.)
    - Some students believe it will reach a 'terminal' (constant) speed where it is no longer accelerating. Ask: *Why? What stops the ball from just going even faster?* (It is important to discover the student's reasons for thinking this. For example, a reason such as 'the ball cannot go fast enough to use up all its speed' shows some confusion. Terminal speed can in fact occur with a long enough track. The idea is that air resistance, which pushes back against the object, tends to get greater as the speed of the object increases. At a large enough speed, the air resistance is pushing back with enough force that all the forces on the object are balanced, and the object no longer accelerates, and so continues at constant speed. For example, a parachute can create lots of air resistance (or drag) so that a skydiver can fall at a constant speed instead of getting faster and faster.)
- If you were shown two graphs of balls rolling downhill, how could you decide from the graphs which ball had a bigger acceleration?
    - Bigger differences in the length of the strips represent a bigger increase in speed, which is a bigger acceleration.
- What would you expect the streamer graph to look like if the ball kept accelerating at a constant rate?
    - Some students may realise that there should be a constant difference in the lengths of the streamers.