re(Solve) MATHS BY INQUIRY

# MODELLING MOTION

DEVELOPING MATHEMATICS CONCEPTS THROUGH STEM ACTIVITIES

# Teachers' Guide



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Australian Academy of Science

aamt

# Modelling Motion: Developing Mathematics Concepts Through STEM Activities

## Rationale

STEM education is recognised as essential for citizens to participate in a 21st century society and to contribute to Australia's future capacity to develop a strong economy through scientific and technological innovation. There are many moves to strengthen STEM education in Australian schools, but it is rare for these initiatives to treat mathematics as making other than a minor contribution.

These lessons engage students in STEM activities in order to advance their mathematical concepts, rather than just use their existing mathematical knowledge in a superficial way.

The topic consists of practical, inquiry-based lessons, in which students make mathematical models of a variety of motions and forces, using graphs and other mathematical tools. They engage with the power of mathematics to build transferable mathematical modelling skills. Lessons are designed to demonstrate the role of mathematics as a key tool to represent, interpret and understand data obtained from practical STEM activities.

## Background

Many of the lessons in *Modelling Motion* are based on the work of Galileo Galilei, one of the most significant figures in the history of mathematics and science. Galileo was born on February 15, 1564, in Pisa, Italy, and died on January 8, 1642, near Florence. He was the son of a lute-player, and was himself a musician, but is known best for his advances in our understanding of the workings of the natural world.

Galileo was an outstanding natural philosopher (scientist), astronomer, and mathematician, who made fundamental contributions to the study of motion, astronomy, and the strength of materials, and contributed to the development of the scientific method. He insisted that the natural world could be understood through mathematics, changing the science of his day from a verbal, qualitative account, to a mathematical one in which experimentation became a recognized method for discovering the facts of nature. His discoveries with the telescope revolutionized astronomy: he was able for example to measure the heights of the mountains on the Moon using their shadows.

Galileo's legendary experiment where he dropped objects from the leaning tower of Pisa (to prove that all objects fall at the same rate) refuted Aristotle's assertion that the speed of fall is proportional to the mass of an object (that is, heavier objects fall faster). This intuition is still held by many people. (Surprisingly, many historians think this experiment may never have been conducted.)

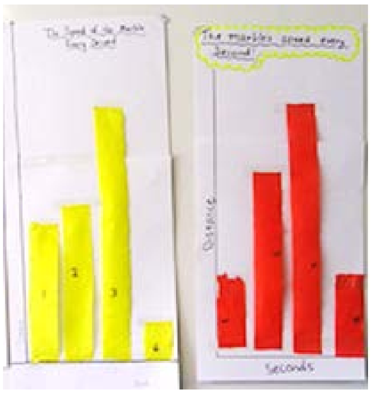
One problem with experimenting with falling objects is that they gather speed very quickly, making it difficult to observe them accurately, so Galileo used an inclined plane (e.g. a ramp or sloping table) to slow the motion down so that it was possible to measure the speed of the ball.

In this unit, we use some of Galileo's ideas to slow down the motion of objects so that they can be observed and measured. Students will investigate constant speed (Lesson 1); acceleration on a slope (2) and in free fall (3); deceleration on a slope and from friction (4); using unbalanced forces to cause acceleration (5,6); and motion in two dimensions (7).

Further background information, definitions and explanations of the physics can be found in Appendix C.

## The use of streamer graphs to model motion

Paper streamers are used in many of the lessons to record the distances that objects travel in successive 1 second intervals. A streamer is laid out next to the path of the moving object, a metronome is started, and students place markers to show the object's position at each tick of the metronome. The streamer is then cut into sections and arranged as a column graph.



While it may be tempting to replace the streamer graphs with tables of values, or graphs drawn from numerical data collected through measurement alone, we regard it as important not to do so (except in the case of *Lesson 3: Falling Balls* where measurements of time and distance need to be taken). The streamer graphs provide a direct representation of the distances travelled each second, allowing students to focus on the interpretation of the data.

Using different coloured streamers as indicated in the Lesson Plans and Student Workbooks will allow the streamer graphs created over the course of the lessons to be easily identified and displayed together for the duration of the unit. The interpretation of patterns is facilitated by displaying and discussing graphs from different groups for the same experiment.

## STEM activities within inquiry pedagogy

Lessons follow a specific pattern to assist teachers in introducing inquiry pedagogy without creating too many disturbances in the classroom. The pattern is based partly on the highly successful Japanese Structured Problem Solving lesson pattern (see, for example, Shimizu, 1999). The stages are:

- Introducing the activity and the introductory challenge, for example 'From what height do you need to drop a ball for it to take 1 second to hit the ground?';
- Doing the activity, making measurements, representating the data, recording findings;
- Students sharing their results as part of a teacher-orchestrated whole-class discussion; and finally
- Teacher and students summarizing what has been learned through doing the activity.

Whole-class discussions, which are interspersed throughout each lesson, play an important role in creating classroom communities of inquiry, where learning takes place through teachers and students building on one another's publicly displayed ideas.

# Overview of the Unit

## About the lessons

*Modelling Motion* consists of seven lessons of approximately 90 minutes each. The lessons are presented in two versions — one for upper primary students (Years 5 & 6) and the other for junior secondary students (Year 7) — with Lesson Plans and Student Workbooks provided. While the main activities are the same for both versions, the level of discussion is expected to reflect students' year level. Any additional material in the Year 7 lessons is included as extension material in the Years 5 and 6 lesson plans. Australian Curriculum content descriptors in mathematics and science are identified at the appropriate year levels.

Lessons are sequential and build on the knowledge students have obtained in previous lessons. Lesson 1 is critical in establishing an understanding of how the length of the streamer sections in the graphs relate to the speed of the person or object — something even many Year 7 students struggle to understand.

Ideally, students will complete all seven lessons. An alternative pathway is to complete Lessons 1 to 4 followed by Lesson 7 (the capstone lesson). Lessons 5 and 6 are useful for making the idea of force more concrete, as students make, calibrate, and use forcemeters, but Lesson 7 can be completed without them.

Ideas for projects are included to assist teachers who may wish to extend the unit. Summary information is given below, and the file *ST3_Motion_Projects.pdf* contains detailed information and student handouts.

## Lesson Summary

| Lesson | What do students do? | What do students learn? | Australian Curriculum Links | |
|---|---|---|---|---|
| | | | Years 5 & 6 | Year 7 |
| 1 Walking at Constant Speed  | Students make and interpret streamer graphs to represent distances walked in a second, using a real or virtual metronome to measure one second intervals. | Interpreting what the strips in the graphs represent is a major focus for this lesson, i.e. understanding that the strips in the graph represent both the distance travelled in one second and the speed of the walker. | *Mathematics* ACMSP118 ACMSP119 ACMSP147 *Science* ACSIS090 ACSIS218 | *Mathematics* ACMNA180 ACMSP169 ACMSP171 *Science* ACSIS129 ACSIS130 |
| 2 Rolling Downhill  | Students investigate the motion of a ball rolling downhill on a track. They predict, create and interpret streamer graphs to model accelerating motion. Gravity can be discussed (optional). | Students develop an understanding of acceleration: the ball keeps getting faster and faster, indicated by the streamer sections getting longer and longer. | *Mathematics* ACMSP118 ACMSP119 ACMSP147 *Science* ACSIS090 ACSIS218 | *Mathematics* ACMNA180 ACMSP169 *Science* ACSSU117 ACSIS129 ACSIS130 |
| 3 Falling Balls  | Students use a variety of measuring devices to find the heights from which a ball needs to be dropped to take 0.5 sec and 0.25 sec to reach the ground. Students use their results to predict and measure the height required for the ball to fall for 1 second (and 0.75 sec). | Students see the dramatic effect of acceleration: the total distance travelled increases by a bigger amount with each extra time interval. To develop understanding of acceleration they compare a graph of total distance vs time with a graph of speed like the one in Lesson 2. | *Mathematics* ACMSP118 ACMSP119 ACMNA131 ACMMG135 *Science* ACSIS090 ACSIS218 | *Mathematics* ACMNA180 ACMSP169 *Science* ACSSU117 ACSIS129 ACSIS130 |
| 4 Rolling Uphill  | Students predict and observe the motion of a ball rolling uphill on a track, and then a ball rolling on a flat track with increased friction (e.g. covered with ribbon). Students create and interpret a streamer graph for the uphill motion, and record the effect of friction on the total distance travelled on the flat track. | Students develop an understanding of deceleration: the ball keeps getting slower and slower, meaning the streamer sections keep getting shorter and shorter. Students learn that friction varies with different surfaces, and that it pushes back against the direction of motion. | *Mathematics* ACMSP118 ACMSP119 ACMSP147 *Science* ACSIS090 ACSIS218 | *Mathematics* ACMNA180 ACMSP169 *Science* ACSSU117 ACSIS129 ACSIS130 |

<table>
<tr><td rowspan="2">Lesson</td><td rowspan="2">What do students do?</td><td rowspan="2">What do students learn?</td><td colspan="2">Australian Curriculum Links</td></tr>
<tr><td>Years 5 & 6</td><td>Year 7</td></tr>
<tr><td>5 Measuring Forces<br></td><td>Students make and calibrate their own forcemeters and use them to measure pushes and pulls. Students discover what happens when two forces pull in opposite directions and draw force diagrams to represent the results.</td><td>Students develop a more concrete idea of what force is and how to measure it. They learn that forces have size and direction and can counteract and balance each other. Weight as a force is introduced when students use weights to calibrate their forcemeters.</td><td>Mathematics<br>ACMNA291<br>ACMMG108<br>ACMNA123<br>ACMMG135<br>Science<br>ACSIS090</td><td>Mathematics<br>ACMNA154<br>ACMSP169<br>Science<br>ACSSU117<br>ACSIS129<br>ACSIS130</td></tr>
<tr><td>6 Force and Motion<br></td><td>Students use their forcemeters to investigate the motion of a car or trolley when pulled simultaneously in opposite directions. Students set up their equipment and predict what will happen, before creating streamer graphs to represent the distances the car moves each second.</td><td>Students discover that the motion is acceleration. Intuitive ideas about rate of change are developed through a comparison with graphs from Lesson 2. An optional activity increases understanding of instrument accuracy.</td><td>Mathematics<br>ACMSP118<br>ACMSP119<br>ACMSP147<br>Science<br>ACSIS090<br>ACSIS218</td><td>Mathematics<br>ACMNA180<br>ACMSP169<br>Science<br>ACSSU117<br>ACSIS129<br>ACSIS130</td></tr>
<tr><td>7 Complex Motion<br></td><td>In this capstone lesson, students investigate the motion of a ball in two dimensions as it travels across a sloping table. Students predict and trace the almost parabolic motion of the ball when it is released at different angles and then try to hit a target placed in different positions on the table.</td><td>Students further develop their ideas about acceleration and deceleration, gravity and friction by applying them to a new situation.</td><td>Mathematics<br>ACMMG114<br>ACMSP120<br>ACMSP147<br>Science<br>ACSIS090<br>ACSIS218</td><td>Mathematics<br>ACMNA180<br>ACMMG181<br>ACMSP169<br>Science<br>ACSSU117<br>ACSIS129<br>ACSIS130</td></tr>
</table>

# Teaching Advice

## Special equipment

Please read Appendix A carefully as some equipment may need to be ordered online or will otherwise require some lead time before the lessons. Most lessons use both readily available equipment such as butcher's paper, rulers and markers, and equipment that will need to be sourced from shops which sell hardware, stationery, sewing supplies, discount goods etc.

A full list of the equipment required for each lesson is in Appendix B.

Attempt the activities first yourself to fine-tune your equipment. This will improve the flow of the lesson and the accuracy of the results. Your set-up can then also be used to demonstrate to the class.

## Student workbooks

Each lesson comes with its own Student Workbook. These need to be printed for each student.

As well as providing a place for students to record their predictions, measurements, explanations, reflections, etc, the workbooks for most lessons provide detailed instructions for students to carry out independent experiments.

The workbooks are designed to be folded to make A5 booklets. You just need to print double sided onto A4 paper, selecting double sided printing flipped on short edge, and ask students to fold their printed sheets in half. Best results are achieved by also selecting '*actual size'* printing instead of '*shrink oversized pages'*.

## Group work

Most lessons involve group work. The list of equipment assumes that there are 5 small groups, each comprising 5 or 6 students. However, students should each use their own Student Workbooks to record their predictions, results and reflections.

A streamer graph from Lesson 1 with labelled axes & an informative title

## Creating streamer graphs: tips

When creating streamer graphs, it is important to label the streamer sections before cutting so that sections can be put in order. Label near the centre of each section to avoid 'cutting the numbers in half'.

A horizontal base line should be drawn near the bottom of the butcher's paper so that students can 'line up' their streamer sections.

Labelling the horizontal and vertical axes requires serious thought and discussion, as indicated in the lesson plan for Lesson 1.

All graphs should have an informative title. Establishing the conventions of graphing (title, axes and labels) requires discussion with students about what to include to communicate the meaning of the graph.

## Accuracy

The extent to which the resulting streamer graphs provide plausible models of the motions depends on two factors.

- The accuracy of the placement of the markers.
  - Students can practise walking or releasing balls and placing markers until consensus is reached that the readings are likely to be as good as possible.
  - Collect repeated data.
  - Discuss, where appropriate, how to decide which data to use. Should some data be discarded?
- The duration of the motion.
  - The more streamer sections the easier it is for students to interpret trends (aim for 4 to 6 sections). If the motion only goes for 2-3 seconds, the streamer graphs will have 2 columns, which is not enough to see trends.
  - For activities which use tracks, the length of the track is critical. During initial trialling we used 1m lengths, which were too short and resulted in very poor data. 1.5m lengths give better results.

It is vital to discuss with students, and for them to think about and develop, techniques which will increase the accuracy of their measurements and reduce the sources of error and uncertainty.

## Spaces to use

All activities, except those in Lesson 3, can be done in a regular classroom, however some teachers have also used space outside the classroom e.g. nearby corridors or outdoors.

Lesson 3 requires dropping a ball at least 5m. Photographs in the Lesson Plans and the video *ST3_Motion_3b_Falling_Balls.mp4* show different spaces teachers used during initial trialling.

# Projects

We have included suggestions for student projects that complement and/or extend the unit.

These projects can be adapted to the practices in your classroom, but in this unit they should always involve students in communicating their findings in a polished form to you and other members of the class. Possible formats include:

- Short oral presentations
- Posters
- Written reports
- Video presentations
- Debates or role plays

Students will usually need help in finding appropriate sources of information. If internet access is a problem, it is often possible to download and print information for students and provide it as needed.

Projects can be completed individually or in groups.

| Topic Area | Project | Description | Prerequisite Lessons |
|---|---|---|---|
| The Fastest People in the World | Project 1: Usain Bolt's 100m sprint world record | Students estimate how long it might take Usain Bolt to run 200m, 400m and 800m, and then find the actual world records for these distances. After calculating the average speed in each case, they discuss the differences. | Lesson 1 + Usain Bolt activity |
| | Project 2: Florence Griffith-Joyner's women's 100m world record | Students estimate how long it might take her to run 200m, 400m and 800m, and then find the actual world records for these distances. After calculating the average speed in each case, they discuss the differences. Students also investigate the differences between men's and women's records. | Lesson 1 + Usain Bolt activity |
| | Project 3: Usain Bolt in slow motion | Students use a video of the 100m sprint to calculate Usain Bolt's average stride length, and compare it to their own. They then calculate which part of the race he was running the fastest using a provided table of times for each 10m. | Lesson 1 + Usain Bolt activity |
| | Project 4: World records for 1500 metres freestyle swimming | Students look up the world records and calculate or approximate the speeds involved. They compare different speeds and consider how the speeds have changed over time. | Lesson 1 + Usain Bolt activity |
| | Project 5: World land (and water) speed records | Students research land speed records, focussing on a vehicle/driver of their choosing. They compare the speeds involved to everyday speeds. | Lesson 1 + Usain Bolt activity |
| Galileo and his Experiments | Project 6: Galileo's life and times | Students research a variety of questions about Galileo, including *What were some of his interests outside of mathematics and science? What were some of his most famous discoveries? Why did he come into conflict with the religious authorities? Why do people say that he revolutionised science?* | Lessons 1-4 |
| | Project 7: Whom should we believe? Galileo versus Aristotle | Students learn about Galileo's experiment with dropping/rolling balls, and his conclusions which challenged Aristotle's ideas about motion. They | Lessons 1-4 |

| | | | |
|---|---|---|---|
| | | perform their own experiments using two balls on an inclined track, to see if a heavier ball falls faster. | |
| | Project 8: How did Galileo measure time when there were no clocks? | Students read about how Galileo measured time for his experiments, and then design and construct their own water clock. | Lessons 1-4 |
| Skate Parks, Halfpipes, and Loops | Project 9: Skateboarding, snowboarding, and toy cars | Students explore the roles of gravity and friction in the motion of objects in halfpipes and loops. They consider how differences in gravity and friction would affect the motion. The project can include measurements taken from videos online or from student videos. | Lessons 1-4, Lesson 7 |

For detailed information on the projects, and printable student materials, see *ST3_Motion_Projects.pdf*

# References and Further Reading


Drake, S. (1975). The role of music in Galileo's experiments. *Scientific American, 232* (6), 98-105.

MacDougal, D. W. (2012). *Newton's Gravity: An Introductory Guide to the Mechanics of the Universe, Undergraduate Lecture Notes in Physics.* ISBN 978-1-4614-5443-4. New York: Springer Science+Business Media.

Shimizu, Y. (1999). Aspects of mathematics teacher education in Japan: Focusing on teachers' roles. *Journal of Mathematics Teacher Education, 2*, 107–116.


# Acknowledgements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Kaye Stacey and Lucy Bates of the reSolve team at the Australian Academy of Science commissioned the work and provided guidance and final editing.

# Appendix A - Equipment List by Source

This list is sorted according to where to find or purchase the equipment. The relevant lessons are given in brackets. For a list of equipment for each lesson see Appendix B. Amounts are based on 5 groups of students.

## Equipment from school

- Butchers' paper — 4 to 12 sheets per lesson
- Glue sticks (at least one per group)
- Marker pens (a few per group, different colours for Lesson 7)
- Scissors (1 per group)
- Large pin-board or whiteboard
- Drawing pins or Blu Tack® to display completed work for discussion
- Metre rulers marked in centimetres (one per group)
- 6 glass marbles (one per group plus 1 for teacher) [Lessons 2,4,7]
- 50 small wooden blocks to use as markers e.g. MAB minis (10 blocks per group) OR 1 large packet of Post-It® Page Markers [Lessons 1-4,6]
- 20-25 wooden blocks e.g. MAB flats OR thin textbooks to elevate tracks and tables (4-5 per group) [Lessons 2,4,7]
- 10-15 wooden blocks (approx. 6 cm high) to prop up the launcher tracks (2-3 per group) [Lessons 4,7]
- Masking tape (one roll per group) [Lessons 4,5,6,7]
- Blu Tack® for positioning tracks (one strip per group) [Lessons 2&4]
- Stop watches, tablets or smart phones (at least one per group) [Lesson 3]
- A step ladder [Lesson 3]
- A few tennis balls [Lesson 3]
- A 5m or 8m measuring tape [Lesson 3]
- String, approximately 20m (4m per group) [Lesson 6]
- 10 long rectangular school tables — approximate size L1200 x W600 x H650 mm [Lesson 6]
    - The length and height of the tables is critical for the experiment. The length of the table limits the length of the streamer graph. The height of the table needs to be around half its length, and two tables stacked on top of each other should not be above the students' shoulder heights. See the lesson plan for more details.
- 5 large rectangular school tables [Lesson 7]
- 5 paper cups of water [Lesson 7]
- Tissues (a few per group) [Lesson 7]
- 5 paper targets (printed from lesson plan, 1 per group) [Lesson 7]

## Equipment from a hardware store

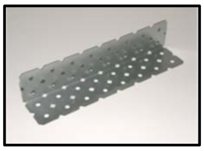
- 6 aluminium tracks (1.5—2m in length, 1 per group plus 1 for teacher) [Lessons 2,4]

  Recommended: Metal Mate 12 x 12 x 1.4mm Aluminium Equal Angle, available in 3m lengths (Bunnings item number 1079519) for approximately $9.50. By cutting these in half you can produce 1.5m tracks which are about the right length.

12 x 12 x 1.4 mm
'v'-shaped aluminium 'track'

- 6 steel ‘launching tracks’ (20—25cm in length, 1 per group plus 1 for teacher) [Lessons 2,4,7]

  Recommended: Carina 40 x 40 x 200 x 1mm Angle Bracket (Bunnings item number MABA2441), approximately $3 per piece.



40 x 40 x 200 x 1 mm Angle Bracket

- 25–30 pieces of 12 mm x 30 cm dowel (1 per student plus 1 for teacher) [Lessons 5,6]

  Available in packets of four from Arbee Crafts for Creating

  http://www.arbee.com.au/shop/dowel

Wooden dowels WO135

- 25–30 small (19mm) cup-hooks (1 per student plus 1 for teacher) [Lessons 5,6]

  Available from hardware shops for approximately $3 for a packet of 25

19mm cup hooks

- 25–30 pieces of tubing, 7–10 cm long (1 per student plus 1 for teacher) [Lessons 5,6]

  One option is to buy 20mm wide rigid electrical conduit from a large hardware shop such as Bunnings. This comes in 2 or 4 metre lengths and is very cheap. But the straight part of these need to be cut to size, which is very tedious.

20mm conduit

  A much better option is to use Tampax Super tampon applicators. These come in packets of 12 at approximately $5 a packet and are available at most supermarkets. Before giving them to students you will need to dismantle the tampons and applicators and just give students the straight part of the applicator.
  **Note:** Other tampon products may not fit the dowels.


Packet of 12 Tampax Suoer tampons with applicator

Straight part to use

## Equipment from a newsagent or discount store or haberdasher

- Paper streamers in different colours. Each lesson specifies a colour so that the streamer graphs will be easy to tell apart and to refer to (see Appendix B for the colours). [Lessons 1,2,3,4,6]
  - Streamers are available very cheaply at variety shops — the old ‘$2 shops’ — and some newsagents, in individual rolls or in packets of mixed colours.
  - One 13m roll of the specified colour is enough for 5 groups of students to complete one lesson (except for Lesson 1 where you will need one 13m roll of blue streamer *for each group* if you decide to do the second part of the lesson in small groups).

A mixed bag of streamers from a ‘$2 shop’

- Ribbon: 7.5m each of 3 different types, cut into 1.5m lengths (1 set per group) [Lesson 4]
  - You will need to select the ribbons carefully so that they fit as neatly as possible into the track, and vary as much as possible in their roughness to give different frictional effects.
- 25–30 poster pins (1 per student) [Lessons 5,6]
- 25–30 pieces of flat elastic (approx. 6mm wide by 30 cm long, 1 per student plus 1 for teacher) [Lessons 5,6]
  - Available from ‘$2 shops’ and haberdasheries

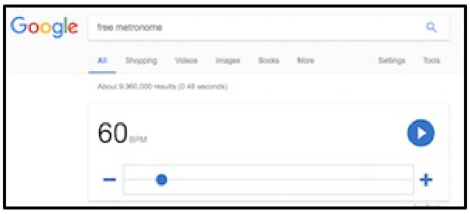
Poster pins

- 5 small rubber balls [Lesson 7]
  - Packets of 6 small rubber ‘hi-bouncing’ balls are available from ‘$2 shops’ for about $3.50

A pack of 6 ‘hi-bouncing’ balls

## Other Equipment

- Metronome (real or virtual — search the internet for 'free metronome') [Lessons 1,2,4,6]
    - Students will need to be shown how the metronome can be used for timing and how to vary the number of beats per minute.
    - The metronome needs to be set at 60 beats per minute during the activities.
    - For all lessons that use a metronome it is best to use only one for the whole class as hearing the sounds from more than one is very confusing.




A free virtual metronome set at 60 beats per minute

- *g Ball* — available for US$35 plus postage from Arbor Scientific at [https://www.arborsci.com/g-ball.html](https://www.arborsci.com/g-ball.html) [Lesson 3]
  **and/or**
  Tablet or smart phone with video capabilities together with video analysis software such as *CoachMyVideo* for Macintosh (free download) **or** similar for android tablets (e.g. *BS Player*) [Lesson 3]
    - To use this software, you need to capture the video and play it back frame by frame.
    - Depending on the number of frames per second when recording (usually 30), the time for the drop can be calculated by counting the number of frames from the time of the drop to the time the ball hits the ground. So, when recording at 30 frames per second (30 fps), 3 frames equals 0.1 seconds, and 8 frames would be approximately 0.27 seconds.
    - Experience from trialling suggests that students find it easy to download and use the software, but may need help to understand how to do these calculations.

A *g Ball* with a built-in timing device

- An outside balcony or stairwell with a drop of at least 5m. (The height from which the ball takes 1 second to fall is 5m). [Lesson 3]
    - If this is impossible, the lesson can be completed by finding the drop for a time of 0.75 seconds and then estimating the time for 1 second.
    - Most trial teachers were able to find places from which to drop the ball. These included the roof of a building and an excursion to a nearby bridge.
- 1 set of digital kitchen scales, accurate to at least 1gram — available from shops such as Target or Kmart for about $12 [Lessons 5,6]

Digital kitchen scales

- 5 toy cars, Duplo or Lego trolleys, trains or similar ([Lessons 5,6]
    - Ensure there is a way to attach hooks and/or tie strings to both front and back. The vehicle will need to roll freely with a hook in either end, i.e. the hooks cannot drag on the table.
    - A heavier car is preferable for Lesson 6, as it will accelerate more slowly.
    - Do not use 'pull back and let go' types.

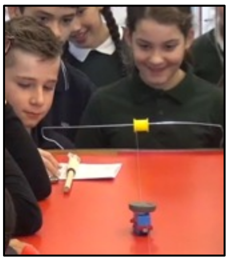
Toy vehicles

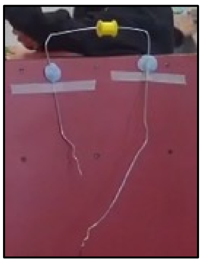
- 25 small bags with 100g weight in each (5 bags per group; beans, coins, etc. are suitable; bags need a small loop or hole, so they can be hung from a hook) [Lessons 5,6]
    - If desired, use an extra bag to hold/hang the 5 smaller bags per group.
    - For lesson 6 it is best to have bags as small as possible so that they do not get in the way.
    - If using coins, you will need $50 worth of 20 cent pieces. These can be obtained from a bank and returned when finished. Each coin weighs approximately 11.2g, meaning 9 coins are very close to 100g. The coins can be weighed before and after the lesson to ensure they are all returned.


A partially filled bag of 20c coins

- 10 pulleys that can be attached to the table tops. [Lesson 6]
    - Each pulley needs to be attached to the table top in such a way that the masses that are hanging from the string will clear the side of the table.
    - Secondary school Science laboratories are likely to have pulleys and stands available for use as shown here.
    - A surprisingly easy and good alternative is to use plastic cotton reels and wire coat hangers as shown in the photos
    - The coat hangers need to be straightened out and attached to the table.
      The middle photo shows a coat hanger attached to the side of a bench using Blu Tack and masking tape.
    - Packets of 20 cotton reels are available from Officeworks for approximately $18.

A pulley and stand





Using cotton reels and wire coat hangers


A pack of 20 plastic cotton reels

# Appendix B – Equipment List by Lesson

| Lesson | Equipment Required |
|---|---|
| 1 Walking at Constant Speed | *Assuming group work for second half of lesson:*<br>• 1 metronome (real or virtual)<br>• 50 wooden blocks (10 per group) to use as markers — e.g. MAB minis — or 1 packet of Post-It® Page Markers<br>• Paper streamers: Red (1 roll) & Blue (5 rolls, 1 per group)<br>• 12 large sheets of butcher's paper (2 for Red graph + 2 per group for Blue graphs)<br>• 5 pairs of scissors (1 per group)<br>• Several glue-sticks (at least 1 per group)<br>• 5 one metre rulers (1 per group)<br>• Marker pens (at least 1 per group)<br>• Large pin-board or whiteboard<br>• Drawing pins or Blu Tack® to attach streamer graphs to the board<br>• Clear space for students to walk across room (can be done outdoors)<br>• Calculators (Year 7 only) |
| 2 Rolling Downhill | • 5 lengths of track (at least 1.5 metres long, 1 per group)<br>• 5 small marbles (1 per group)<br>• 5 thin books to raise the track at one end (1 per group, experiment to find the right thickness)<br>• 10 small pieces of Blu Tack® to position the track (2 per group)<br>• Paper streamer, Green (1 roll, cut into sections a bit longer than the track, 1 section per group)<br>• 5 large sheets of butcher's paper (1 sheet per group)<br><br>*From Lesson 1*<br>• 50 small wooden blocks (10 per group) to use as markers — e.g. MAB minis — or 1 packet of Post-It® Page Markers<br>• 1 metronome (real or virtual)<br>• 5 pairs of scissors (1 per group)<br>• Several glue-sticks (at least 1 per group) |

| | |
|---|---|
| | • 5 one metre rulers (1 per group)<br>• Marker pens<br>• Large pin-board or whiteboard<br>• Drawing pins or Blu Tack® to attach streamer graphs to the board |
| 3 Falling Balls | • Stopwatches (or tablets/smart phones — ideally one per student)<br>• 1 g-Ball **and/or**<br>• One or more tablets or smart phones with video capabilities &<br>    o video analysis software such as *CoachMyVideo* for Mac (free download) **or**<br>    o similar for android tablets (e.g. *BS Player*)<br>• A few tennis balls (1 or 2 for the whole class activities)<br>• Paper streamer: a new colour, 1 roll<br>• 1 one metre ruler marked in centimetres<br>• A section of wall to mark heights on, possibly covered in a paper strip OR use Post-It® Page Markers<br>• One 5m or 8m measuring tape<br>• Step ladder<br>• Outside balcony or stairwell with at least 5m drop |
| 4 Rolling Uphill | • 5 'launching tracks' (1 per group)<br>• 10 thin books or blocks to raise the tracks at one end (2 per group, experiment to find the right thickness.)<br>• Extra thin books for students to adjust the heights<br>• Paper streamer: Purple, 1 roll<br>• 5 sets of 2 or 3 different ribbons the same length as the 1.5m track (1 set per group)<br>• 5 large sheets of butcher's paper (1 sheet per group)<br><br>*From Lessons 1 and 2*<br>• 5 lengths of track (at least 1.5 metres long, 1 per group)<br>• 1 metronome (real or virtual)<br>• 50 small wooden blocks (10 per group) to use as markers — e.g. MAB minis — or 1 packet of Post-It® Page Markers<br>• 5 small marbles (1 per group)<br>• 5 pairs of scissors (1 per group)<br>• Several glue-sticks (at least one per group)<br>• 5 one metre rulers (1 per group)<br>• Marker pens<br>• Masking tape (a few pieces per group)<br>• Large pin-board or whiteboard<br>• Drawing pins or Blu Tack® to attach streamer graphs to the board |
| 5 Measuring Forces | • 1 assembled forcemeter, for demonstration<br>• 25–30 pieces of 12 mm x 30 cm dowel (1 per student, plus 1 for teacher)<br>• 25–30 poster pins (1 per student, plus 1 for teacher)<br>• 25–30 pieces of plastic tubing, 7–10 cm long (1 per student, plus 1 for teacher)<br>• 25–30 pieces of flat elastic, 6mm wide x 30cm long (1 per student, plus 1 for teacher)<br>• 25–30 small (19mm) cup-hooks (1 per student, plus 1 for teacher)<br>• 5 rolls of masking tape (1 per group)<br>• 5 pairs of scissors (1 per group)<br>• 25 small bags with 100g mass in each (5 bags per group; beans, coins, etc. are suitable; bags need a small loop or hole, so they can be hung from a forcemeter hook)<br>• 5 toy cars or Duplo or Lego trolleys, or similar<br>• 5 tables (any size)<br>• 1 set of digital kitchen scales (for optional mass estimation activity) |

| | |
|---|---|
| 6 Force and Motion | • 10 rectangular school tables – approximate size 1200 x 600 x 650 mm (2 per group)<br>• 10 pulleys that can be attached to the table tops (2 per group; can be made from cotton reels and coat hanger wire)<br>• 20m of string (approximately 4m per group)<br>• Paper streamer (2 rolls, any colours)<br>• 10 large sheets of butcher's paper (2 sheets per group)<br>• 1 set of digital kitchen scales<br><br>*From Lessons 1 and 5*<br>• Students' forcemeters constructed in Lesson 5 (a few per group at least)<br>• 5 toy cars or trolleys (1 per group)<br>• 25 bags with 100g weight in each (5 per group)<br>• 5 pairs of scissors (1 per group)<br>• 1 metronome (real or virtual)<br>• 50 small wooden blocks (10 per group) to use as markers — e.g. MAB minis — or 1 packet of Post-It® Page Markers<br>• Several glue-sticks (at least one per group)<br>• 5 one metre rulers (1 per group)<br>• Marker pens<br>• Large pin-board or whiteboard<br>• Drawing pins or Blu Tack® to attach streamer graphs to the board |
| 7 Complex Motion | • 1 assembled table with launching track & ball<br>• 5 small rubber balls<br>• 10 large sheets of butcher's paper (2 sheets per group)<br>• 5 paper cups of water<br>• A few paper tissues per group<br>• Marker pens in different colours (3-4 per group)<br>• 5 copies of the paper target found at the end of the lesson plan.<br><br>*From Lessons 1,4,6*<br>• 5 launching tracks (1 per group)<br>• 5 large rectangular school tables (1 per group)<br>• 20—25 small flat wooden blocks to use to prop up the back legs of the tables — e.g. MAB flats<br>• 10—15 wooden blocks (approx. 6 cm high) to prop up the launching tracks<br>• Blu Tack® to connect blocks & launching tracks<br>• 5 pairs of scissors (1 per group)<br>• Masking tape (a few pieces per group)<br>• Large pin-board or whiteboard<br>• Drawing pins or Blu Tack® to attach the traced paths to the board |

# Appendix C - Background & Definitions

The concepts explored in *Modelling Motion* are explained here in varying detail, along with a small part of the history behind them. Each section starts simply, then is developed to give a more nuanced explanation. It is not expected that students understand all the concepts in the depth given here, but you may find the extra information valuable.

## Speed

[All lessons]

Speed is defined as the distance travelled per unit time. So, for example, if I travel 10 metres in 5 seconds, my speed is 2 metres per second.

Students may think of speed in less formal, less numerical ways. They may only use the words slow, fast, faster, slower, too fast etc. to describe speed. They will all have a physical feeling of speed. This unit offers a way to quantify the physical experience of speed by linking it to the distance travelled in one second. Each strip in the streamer graphs is the distance travelled in one second. Students realise that a longer strip means a faster speed.

Many different units can be used to express speed — for example, speed may be expressed in kilometres per hour, or metres per second. The speed of the growing crack in our dining room wall might be given in millimetres per year. Students often believe that to express speed ‘properly’ it must be given in kilometres per hour. This not the case and doing the arithmetic to convert speeds to kilometres per hour is not a focus for these lessons.

## Acceleration

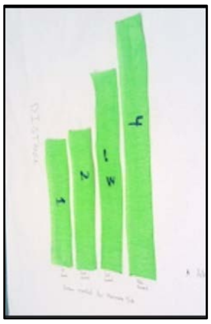
[Lessons 2,3,4,6,7]

Acceleration is often thought of as ‘speeding up’. A better way of expressing this is to say ‘going faster and faster’, to try to emphasise that the speed keeps increasing.

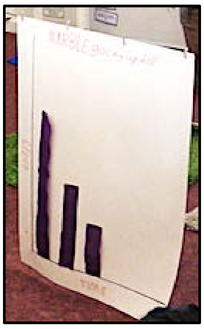
A broader definition of acceleration is ‘a change in the motion of an object’. This can be speeding up, slowing down (also called deceleration: in Lesson 4), or just changing the direction of the motion (not dealt with in these lessons).

***In these lessons we will be using acceleration to mean ‘going faster and faster’ and deceleration to mean ‘going slower and slower’.***

Students observe accelerating/decelerating motion, and then see it represented in the streamer graphs (as the strips get longer and longer, or shorter and shorter). In these experiments, the acceleration will be constant, i.e. the object gets faster by the same amount each second, but this will not be perfectly reflected in the streamer graphs due to experimental error. Students will be focusing on identifying that acceleration is occurring, not finding numerical values or proving that the acceleration is constant.



Streamer graph showing acceleration

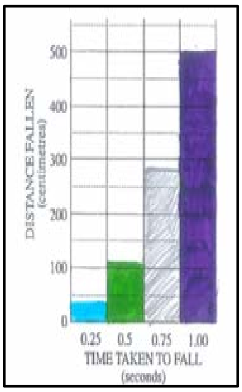


Streamer graph showing deceleration

As students observe the ball, we have found that moving a finger along the track and asking students to describe the motion of the ball at each point helps focus students on the speed of the ball and gives the teacher insight into students' understanding of what is happening. For example, some students believe that they can see a point at which the ball suddenly starts speeding up or slowing down. The streamer graphs are intended to clarify that the speed is in fact changing all the way along the track.

Students encounter deceleration for a ball rolling up a slope (Lesson 4) and produce a streamer graph. As they experiment they will also see that the ball slows to a stop, then starts rolling back down the track. It is important for them to understand that it is the pull of gravity down the slope that is causing *both* these motions. These lessons do not explicitly discuss that deceleration can be thought of as 'acceleration in the opposite direction to the motion', i.e. negative acceleration.

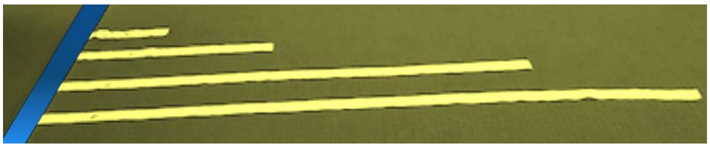
In Lesson 3, students encounter a different type of graph that also shows acceleration. They time a falling ball and record how far it travels in 0.25seconds, 0.5s, 0.75s and 1s after being released. They then draw a graph based on these *total* distances travelled. This gives a graph with columns that are theoretically in the ratio 1 : 4 : 9 : 16, which is not the same increase each time (although experimental error may obscure this). Students will reason from this graph that the ball is accelerating, since it travels more than double the distance in double the time. The graph also gives students an understanding of how large an effect accelerating motion has on the total distance travelled.




Total distance graph showing acceleration.

Students then use this data to construct a streamer graph so that they can make links with the 'Green graph' made in Lesson 2. The strips in the new graph are the distance travelled *each quarter second*. This can be thought of as the speed, but in 'centimetres per quarter second'. This gives a graph with columns theoretically in the ratio 1 : 3 : 5 : 7, which is the same increase each time. This graph will not be 'perfect', but will probably be more accurate than the Green graph, allowing students to more clearly see the increase in speed.

(A note on the ratios of columns: in theory, starting from zero speed, and with constant acceleration, the total distance travelled depends on the square of the total time, i.e. the total distance after 1,2,3,4,5 seconds fits the pattern 1,4,9,16,25. This means that the distance travelled in *each second* will fit the pattern 1-0,4-1,9-4,16-9,25-16 which is 1,3,5,7,9.)



A streamer graph on the floor, showing distance per quarter second

## Force

[Lessons 2-7, especially Lessons 5&6]

A force is a push or a pull.

Examples of forces can 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'. Also, a force might not be strong.

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.

### Force and Acceleration

Students understand intuitively that when force is put on an object, the object tends to move. This unit introduces the idea that this movement is acceleration (getting faster and faster).

Lessons 5&6 develop the idea that for acceleration to occur, the forces on an object need to be unbalanced (e.g. one force pulling left, another unequal force pulling right). The game 'tug of war' is a good example of this: if both sides are pulling with the same force, the whole thing stays stationary. If one side pulls harder, everyone accelerates in that direction.

Although not strictly necessary for this unit, a more complete understanding of force and acceleration includes the idea that an object moving at constant speed is like an object with zero speed, in that all the forces on it are balanced. If the forces were unbalanced, the object would be accelerating (changing speed and/or direction). Newton's *First Law of Motion* could be summarised as "An object stays still (or at constant speed in a straight line) unless acted on by an unbalanced force." Expressing it another way, "An unbalanced force causes a *change* in motion (i.e. acceleration)."

Common confusions around force and motion include:

- If an object is stationary, there are no forces on it. [Usually not true. There are forces on it, but they are cancelling each other out.]
- If an object is *moving*, the forces on it must be unbalanced. [Not always true. The object could be moving with constant speed, meaning balanced forces.]

## Gravity

[Lessons 2-7]

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.
- 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, as well as objects in the atmosphere 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 Earth 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 acceleration due to gravity, *g*, is about 9.8m/s per second for any object near the Earth's surface. In these lessons we approximate this to 10m/s per second (i.e. a falling object's speed will increase by about 10m/s every second).

The *force* of gravity in fact depends on the mass of the object. See below for a discussion of mass and weight.

A more complex explanation of gravity is that it exists between any two objects that have mass. The size of the attraction (force) between the objects depends on both their masses and how close together they are, but the acceleration of each object only depends on the mass of the other object and the distance between them. All objects on the Earth's surface are essentially the same distance from the centre of the Earth, and so they have essentially the same acceleration.

### Mass and Weight

[Lessons 5,6]

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 gravitational force pulling the object down. For example, 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 *weigh*t of about 10 Newtons". When we pick up an object, we feel its weight through the amount of force we need to use to stop the object falling to the ground.

In these lessons, students will convert masses (in grams) to weights (in Newtons) using the approximate relationship of 100g : 1N.

The formal relationship between weight and mass is: *weight = mass x acceleration due to gravity*, or $W=mg$. The acceleration due to gravity, *g*, is about 9.8 m/s per second for any object near the Earth's surface. In these lessons we approximate this to 10m/s per second (i.e. a falling object's speed will increase by about 10m/s every second).

On the moon, 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.

### Acceleration due to gravity on a slope

The acceleration is caused by the pull (force) of gravity directly downwards on the ball. This pull is called the *weight* of the ball. When the track supports some of this weight the acceleration is reduced. The acceleration is shown by the arrows below.

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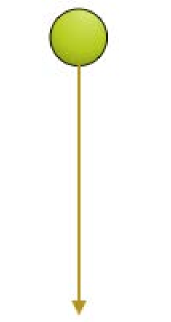
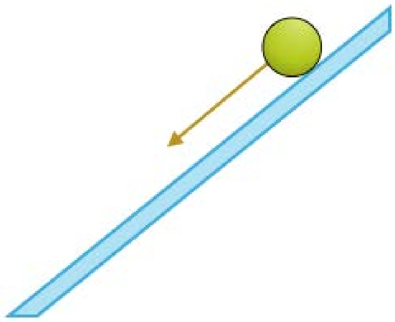
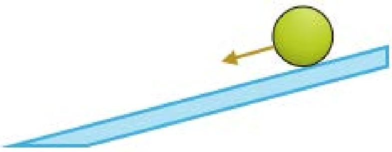
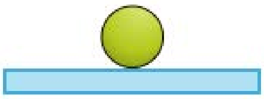
|  |  |  |  |
| A falling ball accelerates directly down. | The track is supporting some of the weight of the ball, so the ball accelerates down the track at a slower rate than a falling ball. | The track is supporting more of the weight of the ball, so the ball accelerates down the track at an even slower rate. | The track is supporting all the weight of the ball, so the ball is not accelerating. |
| What happens if the ball is released with zero speed? | | | |
| The ball falls directly down, getting faster and faster. [Lesson 3] | The ball gets faster and faster as it moves down the slope. The increase in speed every second is smaller than for a falling ball. [Lesson 2] | The ball gets faster and faster as it moves down the slope. The increase in speed every second is smaller than for a falling ball or a steep slope. [Lesson 2] | The ball does not move. |

It is important to understand that rolling up the slope involves exactly the same forces and acceleration. This time the ball is moving in the opposite direction to the force, so instead of speeding up it gets slower and slower [Lesson 4]. Eventually it stops for an instant, and then starts rolling back down the slope, getting faster and faster.

## Friction

[Lessons 2-7]

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 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 discussed in 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 a variety of factors that affect how much friction there is between two surfaces. For example, the heavier an object is the more friction force it will experience.

## Accuracy and Error

If we say a measurement is accurate, we mean that it is very close to the real thing being measured. Accuracy in experiments is about whether we managed to measure what actually happened. ‘Error’ means the difference between what happened and what was measured.

Students will need to practise taking measurements carefully (i.e. marking the position of the object at each metronome tick) and stay focused during the experiments.

Sometimes it is very difficult to measure accurately. Scientists must design experiments so that it is as easy as possible to get good measurements. In these lessons, there will be some error due to unavoidable factors such as human reaction time.