**Physics Module 5: Advanced Mechanics**

## Table of contents

[Teaching the Year 12 modules 3](#_Toc38363787)

[Course overview 3](#_Toc38363788)

[Module summary 5](#_Toc38363789)

[Big ideas 5](#_Toc38363790)

[Relationship to other modules 6](#_Toc38363791)

[Core concepts 6](#_Toc38363792)

[Gravity 6](#_Toc38363793)

[Newton’s laws of motion 6](#_Toc38363794)

[Energy 6](#_Toc38363795)

[Projectile motion 7](#_Toc38363796)

[Uniform circular motion 7](#_Toc38363797)

[Orbital motion due to Newton’s Law of Universal Gravitation 7](#_Toc38363798)

[Energy in gravitational fields 8](#_Toc38363799)

[Opportunities for extended concepts 8](#_Toc38363800)

[Drag in projectile motion 8](#_Toc38363801)

[Derivation of gravitational potential energy 8](#_Toc38363802)

[Underlying assumptions in the equations for Kepler’s 3rd Law and orbital velocity 9](#_Toc38363803)

[Harder examples in uniform circular motion 9](#_Toc38363804)

[Dark matter 9](#_Toc38363805)

[Harder applications of energy concepts 10](#_Toc38363806)

[Simple harmonic motion 10](#_Toc38363807)

[Alternative conceptions and misconceptions 10](#_Toc38363808)

[Projectile motion 10](#_Toc38363809)

[Circular motion 11](#_Toc38363810)

[Newton’s Law of Universal Gravitation 11](#_Toc38363811)

[Conceptual difficulties 12](#_Toc38363812)

[Using proportional reasoning 12](#_Toc38363813)

[Changes in kinetic and potential energy during orbital decay 12](#_Toc38363814)

[Suggested teaching strategies 13](#_Toc38363815)

[Teaching sequence 13](#_Toc38363816)

[Activating prior learning 13](#_Toc38363817)

[Suggested investigations 14](#_Toc38363818)

[Further investigations to extend student understanding 15](#_Toc38363819)

[Appendix 1: Modelling drag force using tracker 17](#_Toc38363820)

[Resources 18](#_Toc38363821)

[Projectile motion 19](#_Toc38363822)

[Motion in gravitational fields 19](#_Toc38363823)

## Teaching the Year 12 modules

The new Stage 6 Physics course was implemented in NSW schools in 2018-2019. This syllabus incorporates new content and learning activities such as depth studies. The syllabus is designed around inquiry questions and formal assessment tasks emphasise the skills for working scientifically.

The Year 12 course provides avenues for students to apply the concepts they were introduced to in Year 11 to motion in two dimensions, electromagnetism, theories of light, the atom and the Universe.

Therefore, pedagogies that promote inquiry and deep learning should be employed in the Physics classroom. The challenge presented by the additional content and the change in pedagogical approach were the catalysts for the preparation of these module guides for Stage 6. These guides are intended to assist teachers deliver Physics effectively by outlining overarching concepts (big ideas), core and extended ideas, strategies for teaching the modules, uncovering of alternative conceptions, and strategies to address them. The guides support the teacher in facilitating the development of deep knowledge structures, such as the relationships between concepts. The module guides do not cover all aspects of the syllabus, as that was not within the scope of the project.

It is essential that teachers note that the module guides do not substitute the syllabus, but only support teachers to teach it. The information contained in these documents are correct at the time of publication. While every effort has been made to eliminate errors, any errors or omission that are identified after the release of these documents will be corrected and released as resource updates. It is recommended that teachers access the [Curriculum website](https://education.nsw.gov.au/teaching-and-learning/curriculum/key-learning-areas/science/stage-6/physics) for the latest version of these documents.

## Course overview

The Year 11 course introduces fundamental concepts of motion, forces, fields, energy and momentum. It provides opportunities for students to develop skills in Working Scientifically, including skills related to the quantitative analysis and modelling of physical systems.

The Year 12 course further develops these concepts and applies them to the analysis of phenomena and technologies that are relevant to society and to contemporary physics. The law of conservation of energy, along with the development of theories and models form common themes across each of the modules. The role of scientific investigation and evidence in advancing our understanding is explored in detail in modules 7 and 8.

Inquiry questions are included in the course content and are used to frame the syllabus. The depth of understanding required to fully address the inquiry questions may vary. This allows for differentiation of the course content to cater for the diversity of learners.

During the teaching of the Year 11 course, it is expected that students have been provided opportunities to develop all seven of the Working Scientifically skills. Ideally, these would be embedded into the teaching of the Knowledge and Understanding components of the course. In preparation for the Year 12 course, students in Year 11 could benefit from work that engages them in the following areas:

* Propose hypotheses, design and conduct valid and reliable practical investigations that effectively use technologies to collect and analyse data. Teachers should look for opportunities to engage students in these beyond where the syllabus explicitly states the need to conduct a practical investigation.
* Construct and analyse graphical data for both primary and secondary sources. This should include describing relationships between variables, particularly time-varying quantities such as displacement and velocity. Emphasis should be placed on extracting qualitative and quantitative information from the gradient and/or the area under a graph.
* Evaluate and improve the quality of data collected. Students should be encouraged to recognise errors, uncertainty and limitations in the data they collect. Practical investigations provide opportunities to practice quantifying errors, including the calculation of absolute and relative errors, along with techniques such as the use of a line-of-best fit to minimise the impact of random errors in measurement.
* Assess the uses, benefits and limitations of various types of scientific models. Models are a powerful tool in science, allowing phenomena to be more easily explained and predicted by capturing and highlighting only the most important features of a system. For example, when analysing gravitational potential energy (GPE) in Module 2, it is beneficial to employ a model in which acceleration due to gravity is a constant 9.8 ms-2 and arbitrarily set $GPE=0$ at the Earth’s surface. This model is suitable for analysing the motion of objects close to the Earth’s surface including projectiles, pendulums and rollercoasters. However, students should also be encouraged to consider the limitations of such models. For example, the model above would not be appropriate, or effective, for analysing the motion of satellites as acceleration due to gravity cannot reasonably be considered constant over large distances.
* Study the rates of change of quantities including displacement, velocity, temperature and energy to support deeper insights into physical phenomena. Rates of change are particularly important to the understanding of electromagnetism in Year 12.
* Collect relevant information from secondary sources and determine the accuracy, reliability and validity. Many of the investigations will require students to obtain information from the Internet or other sources. Students will benefit from learning how to access suitable information and appreciate how new evidence can change prevailing views.
* Develop an awareness of the interconnectedness of physics concepts, including the application of conservation of energy and momentum to the understanding of diverse phenomena.
* Develop confidence in the selection and manipulation of units for physical quantities. Students should be provided opportunities to practice converting units, along with calculating and communicating quantities using scientific notation.
* Create and analyse diagrams that represent vector quantities including free-body, field and ray diagrams. Students should develop confidence in resolving 2-dimensional vectors into their components and in adding multiple vectors to find the resultant.

## Module summary

This module extends students understanding of mechanics. Module 5 explores the following inquiry questions:

* **IQ5-1:** How can models that are used to explain projectile motion be used to analyse and make predictions?
* **IQ5-2:** Why do objects move in circles?
* **IQ5-3:** How does the force of gravity determine the motion of planets and satellites?

This module extends the analysis of motion from one-dimensional and uniformly accelerated motion covered in modules 1 & 2 to include:

* Two and three-dimensional motion
* Non-uniform acceleration
* Special cases such as circular and projectile motion

## Big ideas

In this module, students will use simple models to represent complex phenomena. Models are valuable in explaining and in making predictions. In applying models, it is important to consider any limitations due to their underlying assumptions.

Circular and projectile motion provide suitable models for analysing the orbital motion of satellites/planets and of projectiles launched near the Earth’s surface.

The use of vector diagrams, and the analysis of graphs and energy transformations can further support the understanding of complex motion.

The ability to recognise special cases of motion in diverse phenomena and subsequently select appropriate models and tools is crucial for effective problem solving in Advanced Mechanics.

## Relationship to other modules

This module works well as the first module in Year 12. It builds on ideas about force and motion developed in Modules 1 and 2 in Year 11.

Ideas about fields, projectile motion, circular motion and potential energy that are introduced and strengthened in this topic are built upon in Module 6 (Electromagnetism).

## Core concepts

### Gravity

Locally (near to the Earth’s surface) acceleration due to gravity can be considered uniform. In Module 5, students are required to consider the more general non-uniform nature of gravity.

This module builds upon the understanding of Newton’s laws of motion and energy developed in the Year 11 modules on Kinematics (Module 1) and Dynamics (Module 2).

### Newton’s laws of motion

This module explores the application of Newton’s laws of motion in three important ‘special cases’ for motion, introducing them in the context of the force due to Newton’s Law of Universal Gravitation:

* A force with constant magnitude and direction producing a parabolic trajectory.
* A force with constant magnitude which always acts perpendicular to the direction of motion of an object producing uniform circular motion.
* A force proportional to the inverse square of the distance between two objects producing trajectories that are conic sections. The syllabus focuses on elliptical motion due to the gravitational force, of which circular motion is a special case.

The special cases of projectile motion and uniform circular motion are revisited in Module 6 (Electromagnetism) in the context of the force acting on charges due to electric and magnetic fields respectively. In Module 7, students use concepts developed in this module as they learn about historical measurements of the speed of light which relied on the orbital motion of the moons of Jupiter and Earth’s orbital motion around the Sun.

### Energy

The last part of this module builds on the concepts of work and kinetic and potential energy developed in Module 2, introducing a more general expression for the change in gravitational energy of a system of masses. The concept of a change in potential energy as the negative of the work done by a conservative force is revisited in Module 6 as the more challenging concept of electric potential is developed.

### Projectile motion

Important ideas include:

* Galilean relativity, which implies that motion in horizontal and vertical directions is independent.
* In gravitational fields near the surface of the Earth the force due to gravity is essentially constant, producing a constant downwards acceleration of projectiles.
* For the motion of compact dense at low speeds, the drag force is small enough that it can be neglected. In this case the velocity in the horizontal direction is constant.
* As a result, projectiles follow a parabolic path through the air.

### Uniform circular motion

A force that has a constant magnitude which always acts perpendicular to the direction of motion, a `centripetal force’, will cause an object to move in a circle at constant speed.

Many different forces, or combinations of forces, can provide a centripetal force in certain circumstances:

* friction supplies centripetal force to allow a car to move around a bend (for example, HSC 2004, Q18)
* tension for a mass swung on a string
* the normal force, for a car moving around a banked track, a person in a ‘rotor’ carnival ride or can simulate gravity in a hypothetical rotating space station (for example, HSC 2013, Q30)
* gravity, for example at the top of a vertical `loop the loop’ (for example, HSC 2016, Q18), or to keep an object on the surface of the Earth as the Earth rotates on its axis.

In any situation in which an object is moving in a circle at constant speed, the vector sum of the forces acting on it must be $\sum\_{}^{}F=\frac{mν^{2}}{r}$

### Orbital motion due to Newton’s Law of Universal Gravitation

Newton’s Law of Universal Gravitation describes the attractive force that exists between any two masses as proportional to the product of the masses and inversely proportional to the square of the distance between their centres $F=\frac{GMm}{r^{2}}$. The force of gravity can also be viewed as the force acting on a mass m due to a gravitational field around a mass M. The force of gravity provides a centripetal force for objects such as planets and satellites, resulting in orbital motion, characterised by Kepler’s 3 laws.

Students apply these laws to understand the motion of planets and satellites and, for satellites, relate this to their uses.

### Energy in gravitational fields

The total mechanical energy of an object consists of gravitational potential energy (energy stored in the configuration of the masses exerting gravitational forces on each other) and kinetic energy (due to its motion). The sum of an object’s gravitational potential energy and kinetic energy determines whether that object will remain in orbit around the mass it is attracted to (be it gravitationally bound) or if it is unbound, such that it can move infinitely far from the mass it is attracted to, without `falling’ back inwards in a closed orbit.

Students apply these ideas in the context of satellites to understand the energy changes during an elliptical orbit, how energy costs are minimized when changing orbits and the impact on satellites of loss of energy due to atmospheric drag.

## Opportunities for extended concepts

### Drag in projectile motion

Drag is neglected in the treatment of projectile motion given in the syllabus. Activities such as the [pHet projectile motion](https://phet.colorado.edu/en/simulation/projectile-motion) simulation or videoing projectiles and analysing the motion using the [Tracker](https://physlets.org/tracker/) tool can be undertaken to investigate how drag depends on speed and shape of projectiles and to examine the validity of neglecting drag in a variety of situations. By creating a dynamical model (cartesian), students can use the Model Builder function to add, modify and test for fit different models for air resistance. A range of examples such as [Badminton Projectile Motion: Modelling Air Resistance](https://www.compadre.org/osp/items/detail.cfm?ID=12086) can be found on The Open Source Physics site, with some also including instructions and student worksheets.

Further instructions explaining how to get started with modelling in tracker are included in the appendix.

### Derivation of gravitational potential energy

Students with a calculus background can be taken through the derivation of gravitational potential energy as the negative integral of the work done by gravity moving an object from infinity to some distance, r, from the centre of a massive body such as a planet or star.

### Underlying assumptions in the equations for Kepler’s 3rd Law and orbital velocity

Teachers can also explore the assumptions that have been made in the derivation of orbital velocity and Kepler’s 3rd Law. This can be taught in an inquiry-based approach [using animations](https://lab.nstmf.org/gravity):

* One mass is assumed to be very much larger than the other, so that orbital motion occurs around the centre of mass of the larger mass which is close to the centre of mass of the system.
* Only one gravitational force is assumed to be significant in supplying the centripetal force, which may be only approximately true in some circumstances, such as the James Webb Space telescope (HSC 2010, Q24).

### Harder examples in uniform circular motion

Providing students with experiences of uniform circular motion in a wide variety of physical situations allows them to build a robust understanding of the very general principle that the vector sum of the forces must add to the correct centripetal force if an object is moving in uniform circular motion. Harder examples might include:

* Friction in banked curves. The addition of friction in banked curves requires a robust understanding of the interaction between static friction and the normal force.

### Dark matter

Investigating the orbital motion of planets can be extended to explore the evidence supporting the existence of dark matter. Whilst investigating dark matter is not a syllabus requirement, it represents an important open question in physics and provides an opportunity for students to engage with contemporary physics. Additionally, rotation curves can be introduced as an example of processing data and information to aid analysis, supporting students understanding of the Working Scientifically skills.

Vera Rubin (1928-2016) was an American astronomer whose observations of the orbital speed of stars in the Andromeda galaxy in the 1970’s led to a revolution in our understanding of the universe. She observed orbital speeds for stars that were higher than could be accounted for by the observable mass of the galaxy.

Comparison of theoretical and the observed rotation curves, plots of orbital speed or stars versus their distance from the galactic centre, revealed discrepancies that could not be accounted for. Specifically, the observation of ‘flat’ rotation curves where the rotational velocity of stars remains almost constant as distance from centre increases. This convincing evidence challenges our current understanding of the universe.

[Dark matter and uniform circular motion](https://resources.perimeterinstitute.ca/products/dark-matter-and-uniform-circular-motion) is a learning activity that can be completed as part of a unit of work on dark matter. Students model the evidence described above as they investigate the factors affecting the orbital speed of an object undergoing uniform circular motion.

### Harder applications of Energy concepts

Gravity assist (slingshot effect) relies on conservation of momentum and conservation of kinetic energy to transfer kinetic energy/momentum from a planet to a space probe for the purpose of providing some of the gravitational potential energy required to for the probe to travel to outer planets or beyond the solar system. Students can study the trajectory of a variety of probes, such as Cassini or Voyager, to gain an appreciation of the critical role energy plays in our exploration of space. Developing a deep understanding of these concepts will assist students in answering longer mark extended response questions (such as HSC 2010, Q32).

Investigating potential transfer orbits that could be used by spacecraft to efficiently transit between orbits in the Solar system provide an opportunity to explore energy concepts. [The Planetary Transfer Calculator](https://transfercalculator.com/) is an online tool created by a NSW student that can be used to examine the features of transfer orbits and includes instructions and details about how it was coded.

### Simple Harmonic motion

When objects undergoing uniform circular motion are viewed from a point parallel to the plane of the motion, for example our view of Jupiter’s moons, they appear to be undergoing simple harmonic motion (SHM). Simple harmonic motion is a very important ‘special case’ of motion in physics, which appears in waves, circuit theory and our understanding of the motion of atoms connected by intermolecular bonds which behave elastically, which underlies much of material science. For students studying Mathematics Extension 1, links can be made to the treatment of SHM in that course.

## Alternative conceptions and misconceptions

Addressing the alternative conceptions held by students is an important part of teaching this topic as it deals with motion that the students experience daily and have strong ideas about.

### Projectile motion

Many students believe that there is an upward force on a projectile before it reaches its maximum height, even after substantial explicit teaching. Many learning opportunities are needed to allow students to clarify their understanding of the difference between velocity and acceleration and the necessity for the force on a projectile due to gravity to be directed downwards during its entire motion. These can include:

* graphing position, velocity and acceleration versus time for an object thrown upwards (building on these same graphs for objects on inclined planes in Module 2)
* asking students to draw free body diagrams for a projectile launched vertically (and at an angle) at different points in its motion. This allows students to explicitly examine the consistency of their beliefs about motion with their knowledge of physics.

### Circular motion

Students commonly believe there must be a force in the direction of motion for objects moving in a circle at constant speed and/or that there is an outward, centrifugal force that “balances” inward centripetal force.

An effective formative assessment and learning activity can be done using a record player and a wireless accelerometer or a phone with an accelerometer app. Students are asked to predict the direction of the acceleration when the turntable is rotating at constant speed. Results may be displayed to students in real time (for example using a screen mirroring app) and discussed.

### Newton’s law of Universal gravitation

There are two common alternative conceptions about gravity:

* Large masses exert a larger gravitational force on small masses than small masses do on large masses. See [Derek Muller’s Veritasium](https://www.youtube.com/watch?v=8bTdMmNZm2M) video (duration 4:37) for both evidence of the existence of this alternative conception and an explanation that may help convince students. This explanation is also used in the “Preconceptions in Mechanics” (discussed later).
* There is no gravity in Space. Students believe this because astronauts on the International Space Station are floating. Derek Muller’s video, [Why Are Astronauts Weightless?](https://www.youtube.com/watch?v=iQOHRKKNNLQ) (duration 3:40), is an effective teaching sequence to teach Newton’s cannon thought experiment. Firstly, it forms a transition between projectile motion and orbital motion, so that students are already convinced that it is possible for an object to fall towards earth without hitting it. In a later lesson put up an image of a floating astronaut on the projector and seek students’ opinions on whether there is really gravity in space. Finally, make the link back to their prior experience of Newton’s cannon so they can “put it all together”.

The Journal of ASTA: Teaching Science article “Probing Year 11 physics students’ understandings of gravitation” outlines a range of alternative conceptions relating to gravitation and includes an analysis of a short questionnaire given to Year 11 physics students. The questionnaire consists of 13 questions with diagrams that are designed to identify alternative conceptions held by students and is included in the appendix of the article.

## Conceptual difficulties

### Using proportional reasoning

Students are often required to solve problems on Newton’s Law of Universal Gravitation, Kepler’s 3rd Law and orbital velocity using ratios. This can be challenging for students. This can be addressed by giving students experience in solving problems using a ratio form of Kepler’s 3rd Law

$$\left(\frac{r\_{1}}{r\_{2}}\right)^{3}= \left(\frac{T\_{1}}{T\_{2}}\right)^{2}$$

For questions such as “How does the gravitational force change if one mass is halved and the distance also decreased by half?” students can be led through the process of writing down an expression for the original force:

$$F\_{orig}=\frac{GMm}{r^{2}}$$

then substituting the changes and expressing the new force as a multiple of the original force:

$$F\_{new}=\frac{GM\left(\frac{m}{2}\right)}{\left(\frac{r}{2}\right)^{2}}= \frac{4GMm}{2r^{2}}=2F\_{orig}$$

Students need to use similar proportional reasoning skills in Module 6 as it is commonly required in questions on the force between parallel wires such as “How does the force between the wires change if one current is doubled and the distance halved?”

### Changes in kinetic and potential energy during orbital decay

Understanding changes in potential energy and kinetic energy during orbital decay is challenging for students. Satellites in low Earth orbit lose kinetic energy as they collide with molecules in the atmosphere. No longer having sufficient tangential velocity to maintain their circular orbit (as the force due to gravity at that altitude is larger than the required centripetal force for this lower velocity), they lose altitude. As they lose altitude their gravitational potential energy is converted into kinetic energy in the form of an increased velocity in the downwards direction. While students find it counter-intuitive that the atmosphere slowing a satellite down would result in it having a larger velocity, this is more convincing for them if it is highlighted that this increase in velocity is directed downwards. It is also possible to make a good analogy with the motion of someone on a slippery slide, even though there is friction, the person ends up with a larger final velocity as they have converted some of their gravitational potential energy to kinetic energy.

## Suggested teaching strategies

### Teaching sequence

The order of the inquiry questions in the syllabus works well. It would also be possible to teach the circular motion inquiry question before the projectile motion section without any change to the flow of the module.

### Activating prior learning

#### Projectile motion

The projectile motion section depends upon students’ prior knowledge of the motion of an object thrown or dropped vertically, so it is an effective use of time to begin this module by asking students to draw graphs of the position-time, velocity-time and acceleration-time graphs for vertical motion, and then add in graphs for horizontal position-time, velocity-time (and acceleration-time) as students learn about the independence of motion in these two directions. Graphing activities can be supplemented by asking students to draw free body diagrams for projectiles at different points in their flight (see the section on alternative conceptions).

#### Uniform circular motion

The derivation of the direction and magnitude of centripetal acceleration of is often done using arguments involving vector subtraction of the initial and final velocities, and initial and final positions of an object undergoing uniform circular motion to find vectors representing the change in velocity and displacement. This activity can be preceded by a formative assessment involving calculating changes in velocity of an object moving on a non-circular path (for example a curved track) using vector subtraction, to refresh students’ memory from Year 11.

#### Motion in gravitational fields

A strong conceptual link between projectile motion and orbital motion can be made by beginning this section with [Newton’s cannonball](http://www.eg.bucknell.edu/physics/astronomy/astr101/specials/newtscannon.html) thought experiment and [simulation](https://physics.weber.edu/schroeder/software/NewtonsCannon.html).

#### Working with first-hand data

An excellent source of first-hand data is position-time recordings for the motion of objects obtained using [Tracker](https://physlets.org/tracker/), as outlined in the section on Suggested Investigations. Students can ask questions of the data, and Tracker data particularly lends itself to questioning students about experimental design, such as, does our recording faithfully reproduce the actual motion of the object’ How could we improve the precision of our measurements?

Students can be asked to make choices about what they will graph in order to check whether the assumptions that we have made in our treatment of projectile motion (constant horizontal velocity and constant vertical acceleration) are valid.

Accelerometers (for example those on students’ phones) are also a good source of data that students can analyse. It is very worthwhile for students to have some experience dealing with “noisy” data and making choices about which parts of the data are meaningful for the question they are answering.

#### Web-based inquiry learning resources

An excellent exploration-based resource for this and many other aspects of the Physics syllabus is [Physlets](https://www.compadre.org/Physlets/) Physics. A very appealing feature of Physlets is that students take simulated data and measurements from animated motion directly in order to solve problems. There are no numbers given to students to simply substitute into equations (that is there is no “plug-and-chug”), rather students must think about what information they need to obtain from the simulation to solve the problem.

To choose just one interesting example from the “problems” collection of animations in the projectile motion section of the site is [“Shoot the apple from the tree”](https://www.compadre.org/Physlets/mechanics/prob3_8.cfm). In this problem, the “Monkey and the Hunter” problem is posed to students in three animations, all of which result in the bullet hitting the apple (in this case!) but two of which are incorrect animations. Students must examine the simulations in detail and use their understanding of projectile motion to identify the correct depiction of the problem. In this case they need to make measurements of vertical velocity versus time in the simulation for both the apple and the bullet.

### Suggested investigations

#### Projectile motion investigations:

[Tracker](https://physlets.org/tracker/) is an extremely useful tool for students to use in investigations of projectile motion. It has limitations in precision that can form the basis for useful discussions about experimental design (for example HSC 2018, Q27)

As a practical investigation to collect primary data to validate projectile motion relationships, students can use their phones to video a ball thrown upwards against a uniform backdrop and analyse the motion using Tracker.

Students can manually track, or have the software automatically track the motion of the ball in the horizontal and vertical directions. By plotting graphs of x-position versus time, students can identify that the horizontal velocity remains almost constant. Students can choose an appropriate graph to demonstrate that the vertical acceleration is constant, negative, and has a magnitude of approximately 10ms-2, and justify their choice of graph.

An alternative/complementary practical: Rolling a ball down a slope from different heights so that it rolls off a benchtop with different horizontal speeds (but zero vertical velocity) OR firing a projectile using a projectile launcher. The initial horizontal velocity may be measured using light gates and the range on the floor using Christmas wrapping paper (white side up: ball leaves a visible mark), playdough, carbon paper or sand. The goal of this practical is to demonstrate that a graph of range as a function of horizontal speed is linear, meaning that the time of flight is independent of the horizontal velocity.

#### Circular motion investigations:

An effective practical activity involves measuring the acceleration of an object on a record player turntable using a wireless accelerometer. Students predict the direction(s) in which they think an acceleration will be observed prior to the practical and then compare their predictions to the results, which can be displayed using a projector. A record turntable provides high quality (stable) data, and the fact that it rotates with a known rpm allows students to predict accelerations quantitatively. It is often helpful to students to see that there is an acceleration in the direction of motion when the turntable is speeding up and slowing down, in order for them to feel more confident that there should be no acceleration in the direction of motion when it is moving at a constant speed.

As an alternative or complementary exercise (although the data is significantly noisier), students can use an accelerometer app on their phones, such as “Phyphox”, “The Physics Toolbox Sensor Suite” or “Google Science Journal”. They can investigate the size and direction of the acceleration recorded on their phone when they hold their phone at arm’s length and spin around. They can predict and then measure what happens when they spin faster or slower, or when they hold their phone at different distances from their body.

### Further investigations to extend student understanding

#### Projectile motion

Students could investigate situations in which the assumption made in the syllabus, of a constant downward force acting on the projectile, is no longer valid. Tracker could be used to analyse how the trajectory of an object changes as its size or shape changes, for example a beach ball compared to a ping pong ball, compared to a tennis ball. Alternatively, students could investigate the effect of spin (the Magnus effect) and its importance in ball sports.

#### Circular motion and torque

Advanced students could investigate rolling without slipping as a challenging extension of torque and circular motion, with questions such as, what is the acceleration of an object rolling down an incline? Does shape matter? Does the radius matter?

#### Motion in Uniform Gravitational fields

Students who enjoy programming could produce a numerical model of a 2-body system such as Earth and a satellite, or a 3 body problem such as Earth, the Moon and an Apollo spacecraft (or Earth and the Moon and the Sun), in order to explore the complex and beautiful orbits that exist in these situations. A suitable tool to use is VPython which was designed for producing visual simulations of physical phenomena. [A series of introductory videos](https://www.youtube.com/user/VPythonVideos) can assist understanding. A sample program written in VPython which produces a “figure 8” orbit for a spacecraft around the Moon and Earth is available as a trinket. This is a python program running in the browser on the [Trinket](https://trinket.io/glowscript/2cfa047f4c) website, which students can modify to produce a variety of orbits. Alternatively, students could remove the Moon, by setting its mass to zero.

## Appendix 1: Modelling drag force using tracker

To begin the modelling process, first add a new model to your Tracker project as shown below. For most applications, the dynamic particle model using Cartesian coordinates is the simplest to use. The model builder window will open automatically when a new model is added.

 

Using a dynamic model allows students to specify:

* **parameters**, including the mass of the object
* **initial values**, the initial velocity and position of the object (in terms of x and y components)
* **force functions**, the forces to be applied in the model (also in terms of x and y components)

To apply the model of projectile motion in which only the force due to gravity is operating, use the following expressions for the **force functions**:

$$fx=0$$

$$fy=m\*9.8$$

These expressions, along with those for the initial conditions, can be adjusted through trial and error until the model matches the motion of the object. This model can be adjusted to include a drag force due to air resistance adding a **parameter**, k, representing the drag coefficient to the model and replacing the Force Functions with:

$$fx=-k\*vx$$

$$fy=m\*9.8-k\*vy$$

As before, students can then adjust the drag coefficient, k, until the model matches the observed motion. Students could use this approach to evaluate different models of air resistance or to compare the drag coefficient for a range of projectile shapes.

Further support in using the modelling functions of Tracker is provided in the following resources

* [Tracker free video modelling for physics education (video)](https://www.youtube.com/watch?list=PLYIwRBA8ZhdM3aFDCzPCgf9nRIIrvffUU&time_continue=136&v=WSG1x3klkH0&feature=emb_logo) (duration 3:27)
* [Simulating what you see](https://www.compadre.org/osp/items/detail.cfm?ID=11475)

## Resources

* [Teaching Physics with the Physics suite](http://www.physics.umd.edu/~redish/Book/) by Edward Redish, University of Maryland is an excellent (and very friendly) introduction to physics education research and inquiry-based approaches to teaching physics. As mentioned in this above reference:
	+ Laws, Priscilla W. (2005). Workshop Physics, 2ND Ed. Wiley
	+ Sokoloff, David R, Thornton, Ronald K. and Laws, Priscilla W. (2011). RealTime Physics: Active Learning Laboratories, Module 1: Mechanics, 3rd Ed.
	+ Sokoloff, David R. and Thornton, Ronald K. (2006). Interactive Lecture Demonstrations, Active Learning in Introductory Physics. Wiley

Other sources on inquiry-based approaches to teaching physics

* Jackson, David P, Laws Priscilla W. and Franklin Scott V. (2002). Explorations in Physics: An activity-based approach to understanding the world. Wiley.
* McDermott, Lillian C. and Physics Education Group. (1995). An introduction to Physics and the Physical Sciences. Wiley
* Hieggelke, C J, Maloney, D P, Kanim, Steve. (2011). Newtonian Tasks Inspired by Physics Education Research TIPERs [Addison-Wesley Series in Educational Innovation] and other similar books exist: TIPERS, E&M TIPERS
* Camp, Charles w. and Clement, John J.(2010). Preconceptions in Mechanics: Lessons dealing with students’ conceptual difficulties. 2nd Ed. American Association of Physics Teachers. Second Edition. The main pedagogical idea in this book is “Bridging” using ideas about which students are confident (and are correct) to lead them to correct ideas in other areas where they have alternative conceptions. This book is excellent for teaching the relative motion section in Module 1, but also has chapter dealing with alternative conceptions about the relative size of gravitational forces.
* Arons, A. B. (1996). *Introductory Physics.* Wiley.
* Moore, S. and Dawson, V. (2015) ‘Probing Year 11 physics students’ understandings of gravitation’, Teaching Science: The Journal of the Australian Science Teachers Association, 61(4), pp. 46–55.
* [VISUAL PHYSICS ONLINE](http://www.physics.usyd.edu.au/teach_res/hsp/sp/spHome.htm) Ian Cooper, School of Physics, University of Sydney This website offers a comprehensive range of pdf’s that are tailored to support the Stage 6 Physics course in NSW. Each resource includes clear explanations, activities and makes good use of diagrams to support understanding. Most resources also include differentiated levels of explanation that can be tailored to suit the needs of your students.

### Projectile motion

[PhET projectile motion simulation](https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion_en.html): has some very good lesson plans and instructor resources available. It is necessary to create a free account to access these. Some are inquiry based, for example, [a projectile motion Introduction](https://phet.colorado.edu/en/contributions/view/2839). The post-lab clicker questions are a good resource that will help students think through the effect of drag or the absence of drag, as well as many other variables in projectile motion, such as the impact of the initial angle on time of flight, range and maximum height. Others support the development of students’ working scientifically skills. Most skills are covered in the lab: [Experimental Design: Projectile motion!](https://phet.colorado.edu/en/contributions/view/4314)

### Motion in Gravitational fields

This [orbital simulation](https://lab.nstmf.org/gravity) is fun and very intuitive to use. Students explore non-circular orbits and the orbital motion of objects with similar mass in the space of 10 minutes. For a challenge, ask students to try to create a binary system with two objects of similar mass orbiting each other or a system that has a small mass orbiting a larger mass, which is orbiting an even larger mass.

A resource related to the recent release of an image of a black hole: [Catalyst documentary black hole hunters](https://www.abc.net.au/catalyst/black-hole-hunters/11017424) Feb 2019: From 17:25min-18:35min there is a section where Prof Tamara Davis discusses how we can know where black holes are by their effects on other objects (just like we can’t see the wind, but know it exists from its effects on other objects). She shows a movie of the motion of stars in the centre of our galaxy over the past 25 years demonstrating that they are orbiting a region with nothing visible there. It’s a great visualisation of Kepler’s 1st and 2nd Laws in an at the edge-of-science context.