re(Solve) MATHS BY INQUIRY

MODELLING MOTION

Projects

Contents

These projects will complement and/or extend the unit. The 9 projects represent 3 main themes, offering students choice with some commonality of content. Student sheets for printing are supplied at the end of this document.

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

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

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aamt

Summary of Projects

Projects can be completed individually or in groups.

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.

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 perform their own experiments using two balls on an inclined track, to see if a heavier ball falls faster.	Lessons 1-4
	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

The Fastest People in the World

Projects 1-5 can be started any time after Lesson 1. They build on the Lesson 1 extension activity *How Fast Does Usain Bolt Run?*

Project 1: Usain Bolt's 100m sprint world record

Usain Bolt's 100m sprint world record of 9.58 sec was set in 2009 at the World Athletics Championships in Berlin, Germany. At the time of writing, it is still the world record.

You can watch a YouTube video of Usain Bolt's world record breaking run at https://www.youtube.com/watch?v=By1JQFxfLMM

Bolt also broke his own world record for the 200m race a few days later at the same championships.

- Estimate the time he took for the 200 metres record.
- Estimate how long you think it would take him to run 400 metres, or 800 metres.
- Explain your reasoning.
- Find the world records for 200m, 400m and 800m and calculate the average speeds in kilometres per hour for the world record holders for each of these distances (and for the 100m record if you have not already done this in Lesson 1).
- Explain what you think is happening as the distances increase.
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 2: Florence Griffith-Joyner's women's 100m world record

The women's 100m world record is 30 years old, with Florence Griffith-Joyner's controversial, possibly wind-assisted, record time of 10.49 seconds having been set in the 1988 Olympic final.

You can watch a YouTube video of Florence Griffith-Joyner's world record breaking run at https://www.youtube.com/watch?v=UVSmPBLnSXY

- Estimate the world records for women athletes for 200m, 400m and 800m. How would you expect these records to compare with the world record for 100m? Explain why you think this.
- Find the world records for 200m, 400m and 800m and calculate the average speeds in kilometres per hour for the world record holders for each of these distances (and for the 100m record).
- Explain what you think is happening as the distances increase.
- Some people say that women's sprint records are 'catching up' with the men's. Investigate whether this is true or not.
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 3: Usain Bolt in slow motion

You can watch a slow motion video of Usain Bolt's 2009 world record 100m sprint at https://vimeo.com/54277546

- Can you count the number of strides Bolt takes over the 100 metres? Calculate the average length of Bolt's stride during the race.
- Lay out a piece of paper streamer the length of Bolt's average stride on the floor and see how long it is! How much longer is Bolt's stride than yours and your friends?

You could also use the slow motion to calculate the times at different distances during the run. Other people have done this and have come up with the times at 10m intervals as shown on the following table.

Total times at 10m intervals for Usain Bolt's 2009 world record 100m sprint:

Distance	10	20	30	40	50	60	70	80	90	100
Time (sec)	1.89	2.88	3.78	4.64	5.47	6.29	7.10	7.92	8.75	9.58

Some people say that Usain Bolt sets world records because of his speed endurance — that is, by reaching his top speed and maintaining it better than someone with the same top speed but who decelerates more.

Split times are the times it takes to complete a specific distance in running.

- Calculate the split times for each 10m interval of Usain Bolt's run (that is, how long it took to run each 10m section). When was he running at his fastest?
- Calculate Bolt's average speed for each of the 10m intervals, as well as his average speed over the total 100 metres (you may have already done this in Lesson 1).
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Information for Teachers

The data for these activities come from Wikipedia and other internet sources on world records of athletes (examples of links are given below). There is a lot of data on some of these pages and students who locate them may need help to find the key data they need.

However, as mentioned earlier, these projects do not necessarily require students to search the internet as you can supply them with data when they ask for help with this.

When asked to predict Bolt's record for the 200m, students might suggest 'less than double the time, because once he has achieved top speed he stays at that speed' for the next 100m. This is logical. Other children might disagree, and say 'No, he will get tired and slow down', an argument that clearly applies to the 400m or 800m distances.

Interestingly, Bolt's record for 200m, set a few days after his 100m world record, was 19.19 sec, which is almost exactly double that for the 100m (9.58 x 2 = 19.16 sec): perhaps both arguments are correct in principle, but they almost cancel each other out in practice.

The 'getting tired' argument probably applies to modelling the 400m and 800m races, as Usain Bolt is certainly NOT the fastest man over those distances. Whether he is the fastest over 50m is also open to question and investigation: some of the other sprinters seem to be ahead of him at 50m but he overtakes them between 50 and 100 metres.

One might expect that Usain Bolt's speed increases in the first part of the race (from zero when the gun goes off) and is at or near its maximum in the middle and later parts of the race. This is certainly confirmed by the split times that can be calculated from the table given above. Students may wish to graph Bolt's average speed over successive 10m intervals. Note that this is a different type of graphs from the streamer graphs obtained in the lessons, which would show speed dropping in the last of second as Bolt breasts the tape half-way through the tenth second and slows down after the race has finished.

Close inspection of the slow motion video of the race shows that Bolt's strides are shorter to begin with and lengthen as he picks up speed during the race.

Further Sources of Information

Additional data can be found at the following websites:

- Men's 100m world record progression
  https://www.topendsports.com/sport/athletics/record-100m.htm
- Men's 200m world record progression
  https://en.wikipedia.org/wiki/Men%27s_200_metres_world_record_progression
- Men's 400m world record progression
  https://en.wikipedia.org/wiki/Men%27s_400_metres_world_record_progression

- Women’s 100m world record progression
  https://en.wikipedia.org/wiki/Women%27s_100_metres_world_record_progression
- Women’s 200m world record progression
  https://en.wikipedia.org/wiki/Women%27s_200_metres_world_record_progression
- Women’s 400m world record progression
  https://en.wikipedia.org/wiki/Women%27s_400_metres_world_record_progression
- Men’s and Women’s 800m world record progression
  https://en.wikipedia.org/wiki/800_metres_world_record_progression
- Usain Bolt 10m splits
  http://speedendurance.com/2009/08/19/usain-bolt-10-meter-splits-fastest-top-speed-2008-vs-2009/

There are many other similar projects that students could do. For example, students might be interested in the following:

Project 4: World records for 1500 metres freestyle swimming

Data for men's and women’s world records for 1500 metres freestyle can be found at https://www.revolvy.com/main/index.php?s=World%20record%20progression%201500%20metres%20freestyle&item_type=topic

- Approximate the swimming speeds for some of the records. You could use km/h or m/s. How do these speeds compare to a walking speed?
- Pick two record times that are next to each other, and calculate the average speed for each one. What is the difference in average speed? Do you think it is a large or a small difference?
- Pick two record times that are far apart on the list. What is the difference in the average speeds? Why do you think competitors are swimming faster now?
- Why do you think there are different records for 50m pools and 25m pools?
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

(Approximations rather than exact calculations can put the speeds into context. For example, Kieran Perkins’ 5 April 1992 world record of 14:48.40 minutes for the 1500 metres freestyle meant he was swimming 100 metres in less than 1 minute resulting in a speed greater than 6 kilometres per hour. That is a reasonable walking pace!)

Project 5: World land (and water) speed records

Unlike running and swimming world records, world records such as those for land speed are given directly in average speeds over fixed distances, rather than times.

The video *Donald Campbell Sets Land Speed Record at 403 mph (1964)* shows Donald Campbell setting the last world absolute land speed record of 648.73 kph for a four-wheeled car at Lake Eyre in Australia — see https://www.youtube.com/watch?v=rqvpcX4HoCg

Since 1963, when Craig Breedlove set a record of 655.722 kph in the three-wheel, jet engine driven *Spirit of America,* no wheel-driven car has held the world absolute land speed record — see https://en.wikipedia.org/wiki/Land_speed_record

- Choose one or two of the records in the list (https://en.wikipedia.org/wiki/Land_speed_record) to research. You could:
    - Compare the speed to other common speeds to make it easier to visualise. You could calculate (or approximate) how long it would take the vehicle to travel from your home to your school.
    - Describe any interesting features of the vehicle and find a picture of it.
    - Introduce the driver and explain some of the hard work that went into the vehicle and the record attempt.
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Galileo and his Experiments

These projects can be started after Lesson 4.

As discussed earlier, many of the *Modelling Motion* lessons are based on Galileo's inclined plane experiment, which was used by Galileo to demonstrate that falling bodies accelerate uniformly. Galileo made many other significant contributions to mathematics and science and there are several different possible projects for students to pursue. The ones suggested here include researching Galileo's life and contributions to mathematics and science, investigating Galileo's refutation of Aristotle's view of motion, and making a water clock.

Project 6: Galileo's life and times

Galileo Galilei was one of the most significant figures in the history of mathematics and science.

- Find out about Galileo's life and times. Some questions you might ask include:
    - When and where did Galileo live?
    - 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?
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 7: Whom should we believe? Galileo *versus* Aristotle

Galileo (1564—1642 CE) is said to have dropped objects from the leaning tower of Pisa to test if objects of different mass fall at the same rate.

- Find out about this experiment, and about the theories of Aristotle on falling objects. You can use the information below.

You can watch the first 3:20 minutes of the video *Galileo's 'falling bodies' experiment re-created at Pisa* at https://www.youtube.com/watch?v=_Kv-U5tjNCY to see what happens when two objects are dropped from the top of the leaning tower of Pisa.

Before Galileo did his experiments, most people believed in Aristotle's ideas about force and motion under gravity (Aristotle: 384—322 BCE). They thought that heavier objects fall faster: for example, a cannon ball falls faster than a feather *because it is heavier*. This is what Galileo set out to challenge. In particular he wanted to prove that double the weight does not mean double the speed or acceleration. Galileo knew that some light objects like feathers fall more slowly than heavier ones like cannon balls, but he suggested that this was because of air resistance, rather than the effect of gravity.

The short BBC video, *Galileo's Famous Gravity Experiment*, shows Professor Brian Cox dropping a bowling ball and a feather in the world's largest vacuum chamber at NASA's Space Simulation Chamber in Ohio where there is no air resistance — see https://www.youtube.com/watch?v=QyeF-_QPSbk (first 2:50 minutes).

You might also like to watch another BBC video *Galileo's Experiment*, which includes astronauts on the moon dropping a hammer and a feather — see https://www.youtube.com/watch?v=feFw8Ygn3fk

- Run your own experiment to test whether heavier balls roll down a track faster than lighter balls. Some helpful information is below:

The problem Galileo had when trying to prove his theory by conducting experiments (a new idea at the time) was accurately timing the falling objects. To make them slower and easier to time, instead of dropping balls, he rolled them down a gentle slope.

Hint: To test if one ball is faster than another, you could place both balls on the top of the track, one behind the other, and release them at the same time. If the front ball rolls faster, it should roll away leaving the other one further and further behind. (It might be important to do a second test with the positions reversed. Why do you think this is?)

You may also need to consider other properties that might affect friction and air resistance (such as hardness and smoothness).

- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 8: How did Galileo measure time when there were no clocks?

Galileo studied the motion of objects rolling down an inclined plane. He noted patterns that helped him find out about the motion of falling objects.

He described how he did this in his 1638 book *Discourses on Two New Sciences*:

A piece of wooden moulding or scantling, about 12 cubits [about 7 m] long, half a cubit [about 30 cm] wide and three finger-breadths [about 5 cm] thick, was taken; on its edge was cut a channel a little more than one finger in breadth; having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as possible, we rolled along it a hard, smooth, and very round bronze ball. (Galilei, Galileo, Dialogues Concerning Two New Sciences (New York: Dover) 1954. Translated by Henry Crew and Alfonso de Salvio. See pages 178- 179)

The picture shows a group of physics students trying to replicate Galileo's experiment. (Source: Ascend Administration, Messin with Galileo's Inclined Plane Experiment. From https://www.youtube.com/watch?v=RxSwkaEh9vw)

Physics students replicating Galileo's experiment

In Galileo's time there were no reliable clocks or watches. However, to conduct his 'inclined plane' experiments Galileo needed a way to divide time into equal intervals of less than a second.

People think that at first Galileo relied on music to help him do this. His family were accomplished musicians and he himself played the lute. Conductors of orchestras, as well as good musicians, can divide time into equal intervals with great accuracy. Galileo didn't need to know exactly how long the intervals were in modern standard measurements, such as seconds. He was only interested in the *number* of time intervals. So, Galileo could have used music to time the motion of the ball to a high degree of accuracy.

Later Galileo was said to have used a water clock to conduct his experiments. Water clocks in many different forms had been used since Roman times. Galileo described his water clock in *Discourses on Two New Sciences* like this:

For the measurement of time, we employed a large vessel of water placed in an elevated position; to the bottom of this vessel was soldered a pipe of small diameter giving a thin jet of water, which we collected in a small glass during the time of each descent ... the water thus collected was weighed, after each descent, on a very accurate balance; the difference and ratios of these weights gave us the differences and ratios of the times.

Galileo's water clock worked like a stopwatch. To start the clock, he allowed water to flow into a container. To stop the clock, he stopped the flow of water. To reset the clock, he emptied the container. By weighing the amounts of water in the container, he could then compare the times it took the ball to travel each distance. For example, if twice as much water filled the container, he knew that the time measured was twice as long.

The short video *Galileo and Motion* at https://www.youtube.com/watch?v=MAvPlHAfGbQ explains more about the number patterns he discovered.

- **Challenge:** Can you reproduce, approximately, what Galileo did by building and using your own water clock?
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Information for Teachers

There are numerous sources of information on Galileo's life and work. The USA National Science Foundation funded NOVA website at https://www.pbslearningmedia.org/resource/phy03.sci.phys.mfw.galileoplane/galileos-inclined-plane/#.Ww9YX46bGs0 provides an extended video and other information about Galileo's inclined plane experiment, including discussion questions to use with students. This site also contains video and other resources relating to other aspects of Galileo's discoveries.

Students may wish to find out why Galileo's role in the development of the telescope was so important for both commerce and astronomy and why it upset existing theories and inspired other scientists such as Copernicus and Kepler. There are interesting synergies between scientific and technological development that students may like to explore.

Galileo knew Aristotle was wrong about heavier objects falling faster than light ones because of a thought experiment. Suppose the heavier object can be considered as made up of two objects, each half the total weight, connected by a light string. The combined object then must fall faster than either of the two parts. The hint at the end of P7 is designed to explore this idea. This project extends to the modelling of balls of different mass rolling down tracks. In general, the heavier ball might roll a bit faster than the lighter one because the frictional forces, which will be greater for the heavier ball, do not (generally) increase as quickly as the gravitational force. Friction (unlike gravity) varies according to many factors including weight, materials, speed, and temperature, and is rarely linear. However, the differences caused by friction can be kept small compared with other factors.

The video of what Brian Cox calls 'Galileo's experiment' shows how we can nowadays confirm that it is the air resistance that makes the difference between the fall of a feather and a heavy ball. You may want to avoid the last minute, or so, of the video, where Einstein's theory is mentioned as an alternative, since it may cause unnecessary confusion. Alternatively, you could use the video of the fall of a feather and a hammer (large mass) on the moon, made by the Apollo 15 moonwalkers, though this may raise its own complications, as it is not clear that the only relevant difference between the moon and the earth is earth's atmosphere.

The question of resistance forces raises many possible issues for exploration. A key factor is the area of the moving object presented to the air. So larger balls may experience significantly more resistance than smaller ones. In general, Galileo minimised the effects of air resistance by using small, very heavy metal balls.

A key issue in these projects is the technology of timing. Students may wish to use advanced timing technologies — you may want to encourage this, although perhaps not right from the beginning. Students already know how to make streamer graphs, so if the heavier ball accelerates significantly faster than the lighter ball, its graph should look steeper.

Constructing a water clock can be as simple as you wish. The *Teach Beside Me* home schooling blog *Homemade Water Clock: Ancient Science* at https://teachbesideme.com/homemade-water-clock/ provides detailed instructions on how to create an 'egg-timer' type of water clock using simple materials.

If you want to follow Galileo, all you need is a reservoir of water that can flow into a container that can be put on scales to measure the change in mass. One of the joys of using water is that the mass in grams (g) will be equal to the volume in millilitres (ml). So, students can either measure the mass (imitating Galileo) or the volume. Getting a steady flow (the same volume of water per second) every time you turn on the tap may require some thinking from students. *The flow rate of water will vary with the height of water in the reservoir, so as more water flows out of the reservoir the rate will slow.* If the change in the volume is small the rate can be remarkably steady and therefore the timekeeping remarkably accurate. The best approach is to use a high level of water in a wide container to start, so that the water level drop is small.

This challenge could be given to a class by dividing the class into groups of 3 or 4, each group being given a bucket, plastic or paper cups, and a weighing device. They may also be given a stop-watch, with which to 'calibrate their clock' in seconds (so they can convert the mass of the water collected to elapsed time). They need to know roughly the lengths of times their clock will be required to measure, so demonstrating how a ball rolls down a track for 3 cubits and 12 cubits (a cubit is the length of the forearm) could be part of the introduction to this project.

Further Sources of Information

Below are a few useful websites with further information for teachers:

- *Galileo's experiment with inclined planes* is one of a number of interactive versions of Galileo's experiments at http://www.pbs.org/wgbh/nova/physics/galileo-experiments.html

- Students might also be interested in seeing the video *Hot Wheels Labs: Gravity* at https://play.hotwheels.com/en-au/videos/detail/Hot-Wheels-Labs-Gravity?keywordId=tcm:987-130513-1024&keywordName=Hot%20Wheels%20Labs, which shows young children predicting, observing and finding the relationship between the distances a toy car travels on an inclined plane for 1, 2 and 3 seconds.
- For a comprehensive account see *Galileo's Experiment* at http://galileoandeinstein.physics.virginia.edu/lectures/gal_accn96.htm
- Another comprehensive account, which leads into more advanced mathematics in a gentle way, see *Galileo's Great Discovery: How Things Fall* (MacDougal, 2012, Chapter 2) at http://www.springer.com/cda/content/document/cda_downloaddocument/9781461454434-c1.pdf?SGWID=0-0-45-1366410-p174596162
- Test your knowledge of what happens by trying the Falling Objects section of *Galileo's experiment with inclined planes,* an interactive version of Galileo's experiments at http://www.pbs.org/wgbh/nova/physics/galileo-experiments.html

Skate Parks, Halfpipes, and Loops

This project can be started after Lesson 7.

Many students will have experience skateboarding, scootering or cycling in skate parks, and may well be interested in investigating their experiences. They will have direct experience of the effects of the forces of gravity and friction. They can generate and investigate questions in real life, using videos, or hypothetically.

Students could measure their own speed and acceleration using video and one of several readily available motion sensors and then graph their motion. They should be able to discuss the forces which produce the motion both in terms of their experience and measurements. They can also conduct systematic experiments into the interaction between friction and gravity for different types of motion.

Whether students are investigating actual skateboarding, or videos, emphasise questions that they can investigate by taking measurements that can be used to model the motion. Students can easily analyse video from the web, or data that they collect. Students should discuss the accuracy of the measurements they make, both in terms of errors and random variation, but also the limits of their measurement tools.

Project 9: Skateboarding, snowboarding, and toy cars

There was tremendous interest in the snowboarding halfpipe event at the 2018 Olympic Winter Games at PyeongChang. You can watch a video of 31 year-old Shaun White of the USA win his third Olympic Gold medal for the halfpipe at https://www.youtube.com/watch?v=he03dVkhLTM. The judges were looking for complex tricks, height above the 7m walls, and for riders to land high up on the wall to carry speed into their next trick.

White had also won the gold medal at the Turin and Vancouver Olympic Winter Games in 2006 and 2010, but had failed to win a medal in Sochi in 2014.

While other snowboarders would train in the Southern hemisphere during the Northern summer, White would take a break and do skateboarding. Having turned professional as a skateboarder as a teenager, White became the first person to win in two different sports in Summer and Winter X Games (an annual extreme sports event). To watch Shaun White skateboarding, see *Shaun White's Halfpipe Showdown 2012* at https://www.youtube.com/watch?v=kDcAWaurV_0

Now that skateboarding is going to be introduced for the first time in the Olympics in Tokyo in 2020, White is hoping to become one of only a handful of athletes to win gold medals at both the Summer and Winter Olympic Games.

Skateboarders do seemingly impossible tricks. The video *Tony Hawk Invites Friends to Try the Loop for the First Time – 2008* at https://www.youtube.com/watch?v=TkeCZfG_KaI shows the loop track being constructed and a number of professional skateboarders trying to learn how to 'loop the loop'.

The video *Hot Wheels Labs: Loops* at https://play.hotwheels.com/en-au/videos/detail/Hot_Wheels_Labs_Loops?keywordId=tcm:987-130513-1024&keywordName=Hot%20Wheels%20Labs shows toy hot wheel cars looping the loop.

- Investigate the following to help you explain how gravity (and friction) help or hinder tricks on halfpipes and loops:
  - What effect would *weaker* gravity have on skating? (Imagine skating on a different planet. What would it feel like?)
    - Or *stronger* gravity?
    - Or *no* gravity?
  - What effect would less friction have?
    - Or *more* friction?
    - Or *no* friction?
  - Would it be possible to skate on the Moon or other planets? Why, or Why not, and what would it feel like?
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Information for Teachers

In skateboarding and snowboarding, gaining height during tricks is all about speed, as explained in the video *Shaun White's Gold Medal Run Perfectly Illustrates the Physics of Speed* at https://www.inverse.com/article/41285-shaun-white-olympics-gold-snowboarding-physics-1440 The need for speed can also be seen in both the *Tony Hawk Invites Friends to Try the Loop for the First Time – 2008* and the *Hot Wheels Labs: Loops* videos above.

It is not expected that students will be able to provide detailed mathematical or scientific answers for the questions above, but instead that they give qualitative explanations of their reasoning. However, this project links closely with Lesson 7, where students see the ball rolling down the launching track to gather speed before slowing down as it rolls on the upward sloping table, reaching zero vertical speed at the 'top' of its trajectory. It is at this 'top' point that the skateboarders and snowboarders do their rotational tricks. The means of achieving the rotations is well beyond the scope of this unit, however students should be able to 'see' the point at which the vertical speed is zero.

Even the names of the snowboarding tricks (e.g. the '1440') can provide a stimulus for less complicated investigations.

The Fastest People in the World

Project 1: Usain Bolt's 100m sprint world record

Usain Bolt's 100m sprint world record of 9.58 sec was set in 2009 at the World Athletics Championships in Berlin, Germany. At the time of writing, it is still the world record.

You can watch a YouTube video of Usain Bolt's world record breaking run at https://www.youtube.com/watch?v=By1JQFxfLMM

Bolt also broke his own world record for the 200m race a few days later at the same championships.

- Estimate the time he took for the 200 metres record.
- Estimate how long you think it would take him to run 400 metres, or 800 metres.
- Explain your reasoning.
- Find the world records for 200m, 400m and 800m and calculate the average speeds in kilometres per hour for the world record holders for each of these distances (and for the 100m record if you have not already done this in Lesson 1).
- Explain what you think is happening as the distances increase.
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 2: Florence Griffith-Joyner's women's 100m world record

The women's 100m world record is 30 years old, with Florence Griffith-Joyner's controversial, possibly wind-assisted, record time of 10.49 seconds having been set in the 1988 Olympic final.

You can watch a YouTube video of Florence Griffith-Joyner's world record breaking run at https://www.youtube.com/watch?v=UVSmPBLnSXY

- Estimate the world records for women athletes for 200m, 400m and 800m. How would you expect these records to compare with the world record for 100m? Explain why you think this.
- Find the world records for 200m, 400m and 800m and calculate the average speeds in kilometres per hour for the world record holders for each of these distances (and for the 100m record).
- Explain what you think is happening as the distances increase.
- Some people say that women's sprint records are 'catching up' with the men's. Investigate whether this is true or not.
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 3: Usain Bolt in slow motion

You can watch a slow motion video of Usain Bolt's 2009 world record 100m sprint at https://vimeo.com/54277546

- Can you count the number of strides Bolt takes over the 100 metres? Calculate the average length of Bolt's stride during the race.
- Lay out a piece of paper streamer the length of Bolt's average stride on the floor and see how long it is! How much longer is Bolt's stride than yours and your friends?

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You could also use the slow motion to calculate the times at different distances during the run. Other people have done this and have come up with the times at 10m intervals as shown on the following table.

Total times at 10m intervals for Usain Bolt's 2009 world record 100m sprint:

Distance	10	20	30	40	50	60	70	80	90	100
Time (sec)	1.89	2.88	3.78	4.64	5.47	6.29	7.10	7.92	8.75	9.58

Some people say that Usain Bolt sets world records because of his speed endurance — that is, by reaching his top speed and maintaining it better than someone with the same top speed but who decelerates more.

Split times are the times it takes to complete a specific distance in running.

- Calculate the split times for each 10m interval of Usain Bolt's run (that is, how long it took to run each 10m section). When was he running at his fastest?
- Calculate Bolt's average speed for each of the 10m intervals, as well as his average speed over the total 100 metres (you may have already done this in Lesson 1).
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 4: World records for 1500 metres freestyle swimming

Data for men's and women's world records for 1500 metres freestyle can be found at https://www.revolvy.com/main/index.php?s=World%20record%20progression%201500%20metres%20freestyle&item_type=topic

- Approximate the swimming speeds for some of the records. You could use km/h or m/s. How do these speeds compare to a walking speed?
- Pick two record times that are next to each other and calculate the average speed for each one. What is the difference in average speed? Do you think it is a large or a small difference?
- Pick two record times that are far apart on the list. What is the difference in the average speeds? Why do you think competitors are swimming faster now?
- Why do you think there are different records for 50m pools and 25m pools?
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 5: World land (and water) speed records

Unlike running and swimming world records, world records such as those for land speed are given directly in average speeds over fixed distances, rather than times.

The video *Donald Campbell Sets Land Speed Record at 403 mph (1964)* shows Donald Campbell setting the last world absolute land speed record of 648.73 kph for a four-wheeled car at Lake Eyre in Australia — see https://www.youtube.com/watch?v=rqvpcX4HoCg

Since 1963, when Craig Breedlove set a record of 655.722 kph in the three-wheel, jet engine driven *Spirit of America,* no wheel-driven car has held the world absolute land speed record — see https://en.wikipedia.org/wiki/Land_speed_record

- Choose one or two of the records in the list (https://en.wikipedia.org/wiki/Land_speed_record) to research. You could:
    - Compare the speed to everyday speeds to make it easier to visualise. Calculate (or approximate) how long it would take the vehicle to travel from your home to your school (or choose other places that your class will recognise).
    - Describe any interesting features of the vehicle and find a picture of it.
    - Introduce the driver and explain some of the hard work that went into the vehicle and the record attempt.
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Galileo and his Experiments

Project 6: Galileo's life and times

Galileo Galilei was one of the most significant figures in the history of mathematics and science.

- Find out about Galileo's life and times. Some questions you might ask include:
  - When and where did Galileo live?
  - 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?
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 7: Whom should we believe? Galileo *versus* Aristotle

Galileo (1564—1642 CE) is said to have dropped objects from the leaning tower of Pisa to test if objects of different mass fall at the same rate.

- Find out about this experiment, and about the theories of Aristotle on falling objects. You can use the information below.

You can watch the first 3:20 minutes of the video *Galileo's 'falling bodies' experiment re-created at Pisa* at https://www.youtube.com/watch?v=_Kv-U5tjNCY to see what happens when two objects are dropped from the top of the leaning tower of Pisa.

Before Galileo did his experiments, most people believed in Aristotle's ideas about force and motion under gravity (Aristotle: 384—322 BCE). They thought that heavier objects fall faster: for example, a cannon ball falls faster than a feather *because it is heavier*. This is what Galileo set out to challenge. In particular he wanted to prove that double the weight does not mean double the speed or acceleration. Galileo knew that some light objects like feathers fall more slowly than heavier ones like cannon balls, but he suggested that this was because of air resistance, rather than the effect of gravity.

The BBC video, *Galileo's Famous Gravity Experiment*, shows Professor Brian Cox dropping a bowling ball and a feather in the world's largest vacuum chamber at NASA's Space Simulation Chamber in Ohio where there is no air resistance – see https://www.youtube.com/watch?v=QyeF-_QPSbk (first 2:50 minutes).

You might also like to watch another BBC video *Galileo's Experiment*, which includes astronauts on the moon dropping a hammer and a feather – see https://www.youtube.com/watch?v=feFw8Ygn3fk

- Run your own experiment to test whether heavier balls roll down a track faster than lighter balls. Some helpful information is below.

The problem Galileo had when trying to prove his theory by conducting experiments (a new idea at the time) was accurately timing the falling objects. To make them slower and easier to time, instead of dropping balls, he rolled them down a gentle slope.

To test if one ball is faster than another, you could place both balls on the top of the track, one behind the other, and release them at the same time. If the front ball rolls faster, it should roll away leaving the other one further and further behind. (It might be important to do a second test with the positions reversed. Why do you think this is?) You may also need to consider other properties that might affect friction and air resistance (such as hardness and smoothness).

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Project 8: How did Galileo measure time when there were no clocks?

Galileo studied the motion of objects rolling down an inclined plane. He noted patterns that helped him find out about the motion of falling objects.

He described how he did this in his 1638 book Discourses on Two New Sciences:

> *A piece of wooden moulding or scantling, about 12 cubits [about 7 m] long, half a cubit [about 30 cm] wide and three finger-breadths [about 5 cm] thick, was taken; on its edge was cut a channel a little more than one finger in breadth; having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as possible, we rolled along it a hard, smooth, and very round bronze ball.*

The picture shows a group of physics students trying to replicate Galileo's experiment.

Physics students replicating Galileo's experiment

In Galileo's time there were no reliable clocks or watches. However, to conduct his 'inclined plane' experiments Galileo needed to find a way to divide time into equal intervals of less than a second.

People think that at first Galileo relied on music to help him do this. His family were accomplished musicians and he himself played the lute. Conductors of orchestras, as well as good musicians, can divide time into equal intervals with great accuracy. Galileo didn't need to know exactly how long the intervals were in modern standard measurements, such as seconds. He was only interested in the number of time intervals. So, Galileo could have used music to time the motion of the ball to a high degree of accuracy.

Later Galileo was said to have used a water clock to conduct his experiments. Water clocks in many different forms had been used since Roman times. Galileo described his water clock in Discourses on Two New Sciences like this:

> *For the measurement of time, we employed a large vessel of water placed in an elevated position; to the bottom of this vessel was soldered a pipe of small diameter giving a thin jet of water, which we collected in a small glass during the time of each descent … the water thus collected was weighed, after each descent, on a very accurate balance; the difference and ratios of these weights gave us the differences and ratios of the times.*

Galileo's water clock worked like a stopwatch. To start the clock, he allowed water to flow into a container. To stop the clock, he stopped the flow of water. To reset the clock, he emptied the container. By weighing the amounts of water in the container, he could then compare the times it took the ball to travel each distance. For example, if twice as much water filled the container, he knew that the time measured was twice as long.

The short video *Galileo and Motion* at https://www.youtube.com/watch?v=MAvPlHAfGbQ explains more about the number patterns he discovered.

- Challenge: Can you reproduce, approximately, what Galileo did by building and using your own water clock? Test the accuracy of your clock.
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

Project 9: Skateboarding, snowboarding, and toy cars

There was tremendous interest in the snowboarding halfpipe event at the 2018 Olympic Winter Games at PyeongChang. You can watch a video of 31 year-old Shaun White of the USA win his third Olympic Gold medal for the halfpipe at https://www.youtube.com/watch?v=he03dVkhLTM. The judges were looking for complex tricks, height above the 7m walls, and for riders to land high up on the wall to carry speed into their next trick.

White had also won the gold medal at the Turin and Vancouver Olympic Winter Games in 2006 and 2010 but had failed to win a medal in Sochi in 2014.

While other snowboarders would train in the Southern hemisphere during the Northern summer, White would take a break and do skateboarding. Having turned professional as a skateboarder as a teenager, White became the first person to win in two different sports in Summer and Winter X Games (an annual extreme sports event). To watch Shaun White skateboarding, see *Shaun White's Halfpipe Showdown 2012* at https://www.youtube.com/watch?v=kDcAWaurV_0

Now that skateboarding is going to be introduced for the first time in the Olympics in Tokyo in 2020, White is hoping to become one of only a handful of athletes to win gold medals at both the Summer and Winter Olympic Games.

Skateboarders do seemingly impossible tricks. The video *Tony Hawk Invites Friends to Try the Loop for the First Time – 2008* at https://www.youtube.com/watch?v=TkeCZfG_KaI shows the loop track being constructed and a number of professional skateboarders trying to learn how to 'loop the loop'.

The video *Hot Wheels Labs: Loops* at https://play.hotwheels.com/en-au/videos/detail/Hot_Wheels_Labs_Loops?keywordId=tcm:987-130513-1024&keywordName=Hot%20Wheels%20Labs shows toy hot wheel cars looping the loop.

- Investigate the following to help you explain how gravity (and friction) help or hinder tricks on halfpipes and loops:
  - What effect would *weaker* gravity have on skating? (Imagine skating on a different planet. What would it feel like?)
    - Or *stronger* gravity?
    - Or *no* gravity?
  - What effect would less friction have?
    - Or *more* friction?
    - Or *no* friction?
  - Would it be possible to skate on the Moon or other planets? Why, or Why not, and what would it feel like?
- **Find an interesting way to show other people what you have discovered so that they can learn too.**

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