Physics

Energy Conservation: Power in the wave

Roller coasters are thrilling, hurtling you up and down at high speed. Each one of those dips and rises involves the transformation of energy. And the same sorts of transformation occur in rivers and in the rise and fall of ocean waves, which can be tapped to provide electricity.

In this lesson you will investigate:

• What energy transformations do roller coasters undergo?

• How does the law of conservation of energy influence roller coaster design?

• How is the energy stored in dam water and ocean waves converted into electricity?

Time to spend some energy on learning...

Introduction: Energy Conservation

If you've ever been swimming at the beach and been bowled over by a huge wave, you know how powerful the ocean can be. But did you know that we can actually use that power?

For well over a century humans have depended on fossil fuels – coal, oil, and gas – for energy. But these all put carbon dioxide into the air, which is changing the climate. And even if we can capture the carbon dioxide and store it safely, fossil fuels will eventually run out.

So we have started to find new sources of energy that we can turn into forms that we are able to use. Unlike coal or oil, these "renewable" energy sources are naturally replenished and will never run out. As long as the Sun keeps rising and the wind keeps blowing, renewable energy sources will ensure that we have energy for generations to come.

To use the sea, some projects harness the tides. The flow of seawater in and out with each tide rotates turbines that generate electricity. Other methods use the waves. The recently commissioned CETO plant in Australia uses underwater buoys that generate electricity as the waves move the buoys up and down. The plant is powering a naval base and desalination plant. Scotland's Pelamis Wave Energy Converter uses a different technique, with long hinged tubes floating on the water's surface. They generate electricity as the hinges flex up and down when the waves pass underneath.

But every energy source has its disadvantages as well as advantages. For example, tidal energy systems inevitably affect natural water flows, changing the movement of water in the areas nearby. This can impact sea life there. When we take energy from a natural system we may be affecting ecosystems or geographical processes, such as coastal erosion or the deposition of silt, that rely on that energy. Unfortunately, the law of conservation of energy says that we cannot create energy – we can only remove it from nature, transforming it into a form that is useful to us.

Read the full *Cosmos Newsblog* post here.

Energy transformations occur all around us. From left to right: a CETO buoy transforms wave energy into electricity, leaves transform sunlight into glucose by the process of photosynthesis, muscles transform chemical energy from food into kinetic energy, and hydroelectric dams transform energy in water into electricity.

Efficiency

In most energy transformations only a part of the energy source is changed into the "desired" energy form. In CETO generators, for example, about 80% of the kinetic energy available in the waves is transformed into electricity.

Below are six objects or processes where energy transformations occur. For each one discuss with your classmates and then guess the efficiency of the transformation. For example, how much of the chemical energy in the petrol do you think is turned into kinetic energy in a car? When you have finished your teacher will share the answers with you.

Poll 1
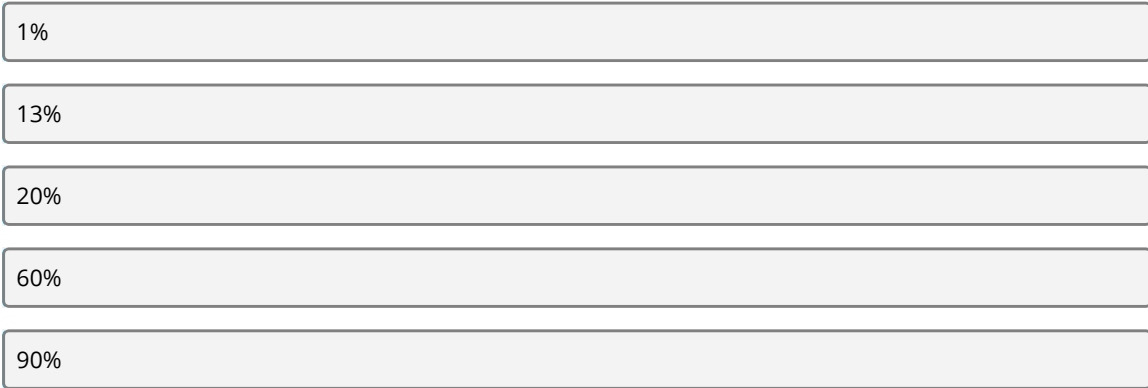
Muscles

You can vote for 1 option on this poll.

1%
13%
20%
60%
90%

📋 Poll 2

Photosynthesis

You can vote for 1 option on this poll.

1%

13%

20%

60%

90%

📋 Poll 3

Hydroelectric dam

You can vote for 1 option on this poll.

1%

13%

20%

60%

90%

Poll 4

Standard (LED) light globe

You can vote for 1 option on this poll.

1%

13%

20%

60%

90%

Poll 5

Petrol car

You can vote for 1 option on this poll.

1%

13%

20%

60%

90%

📊 Poll 6

Electric car

1%

13%

20%

60%

90%

Gather: Energy Conservation

COSMOS LESSONS

2:02

Question 1

Select: The amount of gravitational potential energy possessed by an object such as a roller coaster carriage:

- [ ] increases with its speed.
- [ ] decreases with its height.
- [ ] increases with its height.
- [ ] never changes.

Question 2

Recall: As a roller coaster carriage descends the first hill:

Hint: there may be more than one correct answer.

- [ ] its potential energy is transformed into kinetic energy.
- [ ] its kinetic energy increases with its speed.
- [ ] the main force acting on it is gravity.
- [ ] its potential energy increases.

Question 3

Give examples: Write down two other examples in which an object's energy is transformed back and forth between gravitational potential and kinetic energy.

Calculating energy

If you were designing a roller coaster, how would you make sure that when the carriages had been hauled to the top of the first hill they had just the right amount of energy for a thrilling, but not killing, ride?

What you need is a couple of equations that allow you to precisely calculate the amount of energy the carriages have.

We've already seen that gravitational potential energy depends on height (h, in metres), so:

gravitational potential energy, E_p = ... h ...

How do we fill in the gaps? It probably won't surprise you to learn that energy also depends on mass (m, in kilograms). Intuitively, it takes more energy to move a heavy object than a light one.
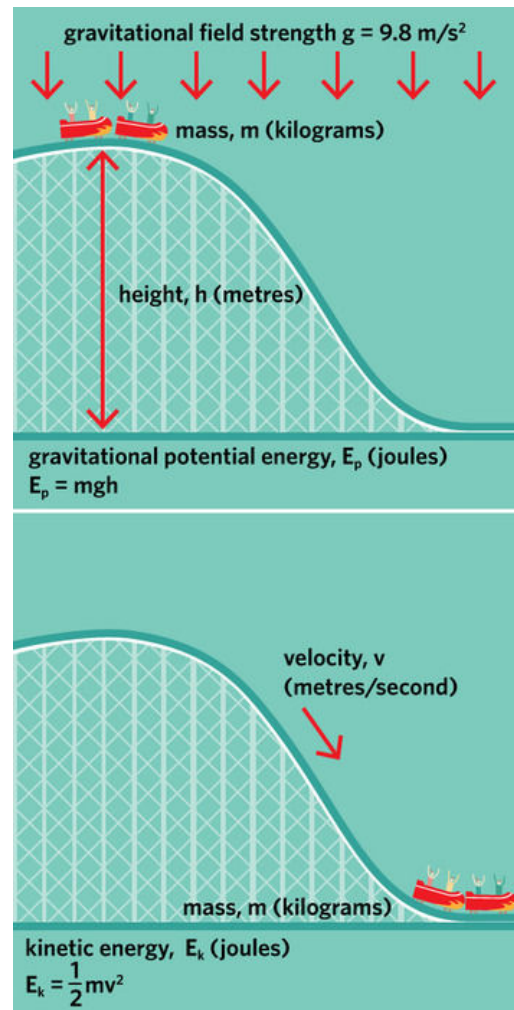
And potential energy also depends on the strength of the gravitational field (g): it takes more energy to lift an object in a strong gravitational field than a weak one. On Earth, g = 9.8 m/s^2.

Putting this together we end up with the following equation:

gravitational potential energy, E_p = mgh

What about kinetic energy – what does the energy in a moving object depend on? Again, mass is a factor. The only other factor is velocity. It's intuitive that a faster-moving object has more energy than a slower-moving one, but it turns out that you need to square the velocity and multiply by a half – we won't prove it here.

kinetic energy, E_k = ½mv^2

gravitational field strength g = 9.8 m/s^2

mass, m (kilograms)

height, h (metres)

gravitational potential energy, E_p (joules)
E_p = mgh

velocity, v (metres/second)

mass, m (kilograms)

kinetic energy, E_k (joules)
$E_k = \frac{1}{2}mv^2$

✏️ Question 4

Identify: A simple roller coaster track is shown below, with the high and low points marked A, B, C and D.

1. Draw a blue circle around the letter marking the point at which the carriage has the highest gravitational potential energy.
2. Draw a green circle around the letter marking the point at which it has the highest kinetic energy.

Below the track are two areas to show how the gravitational potential energy and kinetic energy of the carriage changes.

1. Draw diagonal blue arrows in the "potential increase or decrease" area to indicate whether the gravitational potential energy in each section of track is increasing or decreasing.
2. Draw diagonal green arrows in the "kinetic increase or decrease" area to indicate whether the kinetic energy is increasing or decreasing.

The first arrow of each type is provided.
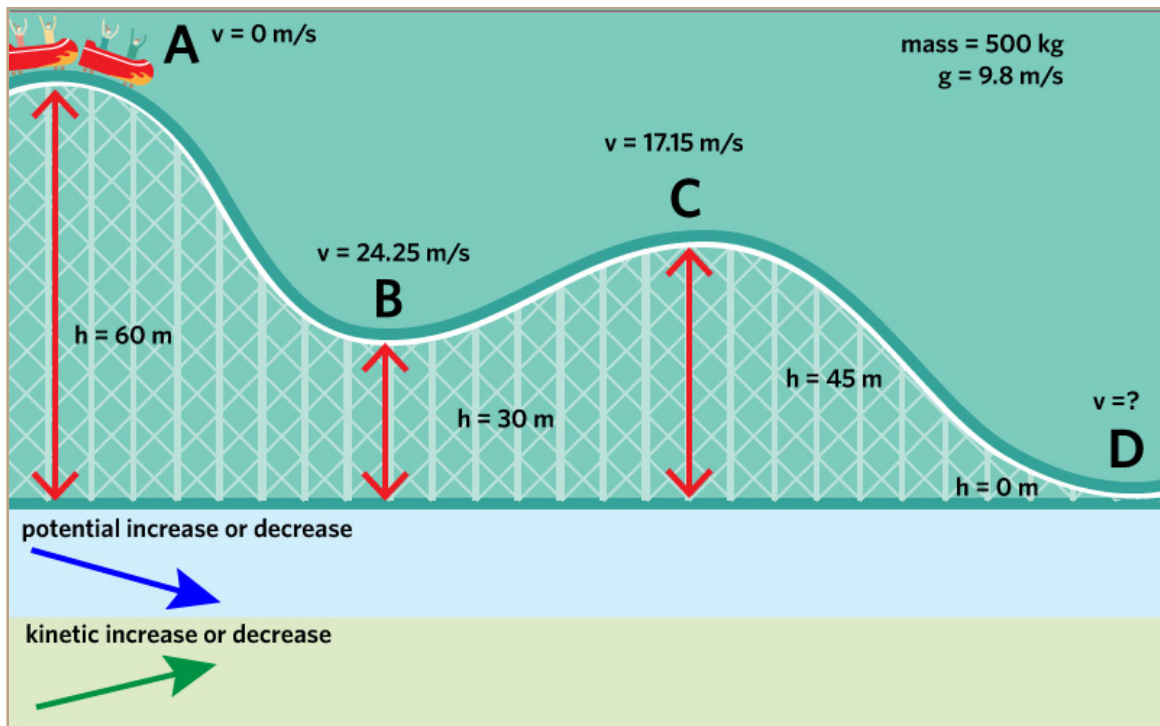
We can use the height (h) and velocity (v) values provided in the sketchpad to make energy calculations, given that the mass of the carriage is 500 kg and the gravitational field strength, g = 9.8 m/s^2.

Below we have calculated the potential and kinetic energies of the carriage at point B. Check the calculations and then it's over to you to calculate these values for the other points.

Important note: For now, assume that no energy is lost in the transformations between potential and kinetic energy.

Calculating the potential and kinetic energy of the carriage at point B:

gravitational potential energy, E_p = mgh

        = 500 kg x 9.8 m/s^2 x 30 m

        = 147,000 J

kinetic energy, E_k = ½mv^2

        = ½ x 500 kg x (24.25 m/s)^2

        = 147,000 J

📝 Question 5

Calculate: Use the equations to calculate, for point A, the carriage's:

1. gravitational potential energy, and
2. kinetic energy.

📝 Question 6

Calculate: Use the equations to calculate, for point C, the carriage's:

1. gravitational potential energy, and
2. kinetic energy.

▦ Question 7

Tabulate: Enter your calculated energy values into the following table. Given that the height of point D is 0 m, fill in the two energy values for this point of the track.

Point	Height (m)	Gravitational potential energy (J)	Speed (m/s)	Kinetic energy (J)	Total energy (J)
A	60		0		294,000
B	30	147,000	24.25	147,000	294,000
C	45		17.15		294,000
D	0		?		294,000

❓ Question 8

Calculate: It's also important to know the maximum speed the carriage will reach.

1. Use the kinetic energy equation to calculate the *speed* of the carriage at point D.
2. Convert your answer from m/s into km/h by multiplying by 3.6.

Note: use the equation editor in the Text tool to show your answer, or do the calculation on paper and upload a photo.

The conservation of energy

Did you notice that the roller coaster carriage would have had a thrilling – or terrifying! – velocity as it reached D? In real life it would be quite a bit slower because of the forces of friction and air resistance, which we've so far been ignoring.

These forces act to slow down moving objects in all everyday situations. But slowing something down means decreasing its kinetic energy. Where does the energy go?

Well, it can't just disappear. The fundamental **law of conservation of energy** states that energy can never be created or destroyed but only transformed from one type to another.

So what forms has the "lost" kinetic energy been transformed into? Some has been transformed as the metal in the wheels and tracks is worn down, but we will focus on two forms more familiar to you – heat, or thermal energy, and sound. Both of these transformations come about as the result of friction. You can demonstrate the principle for yourself by rubbing your hands together – the kinetic energy of your moving hands transforms into sound and your hands warm up.

Question 9

Rewrite: Write a brief explanation of the law of conservation of energy in your own words.

Question 10

Calculate: Suppose that the carriage's *actual* speed at point D was 15 m/s (or 54 km/h).

1. Calculate its kinetic energy in joules.
2. Calculate the percentage of its starting energy that has been converted into thermal and sound energy.

Process: Energy Conservation

COSMOS LESSONS

The massive Three Gorges Dam on the Yangtze River in Hubei province, China.

Energy and water

A vast amount of energy is stored in water. Just think about thundering rivers and waterfalls, heaving tides and powerful waves crashing against the coasts. *Hydro power* is a range of methods for extracting useful energy from the motion of water.

One of the ways that water comes to have energy is simply by being at a high altitude, at the place where it fell as rain or snow. This water has gravitational potential energy. As it runs down to sea level, just like a roller coaster running down into a dip, the potential energy changes into kinetic and other forms of energy.

Consider the Yangtze River in China. It starts 5000 m above sea level in the Tibetan Plateau and then travels 6000 km down to the East China Sea. On the way, it meets the world's biggest dam.

The Three Gorges Dam
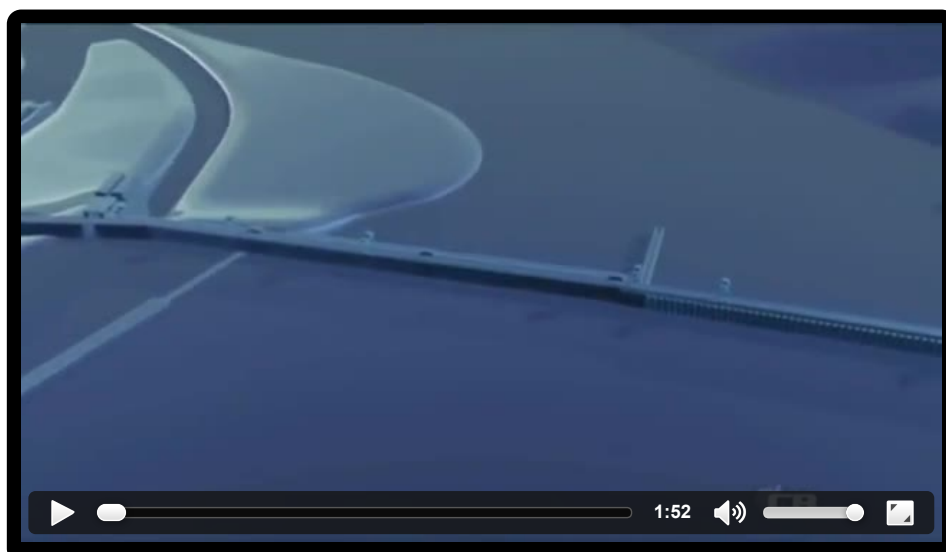
Question 1

Consider: If the Three Gorges Dam's reservoir was not constantly replenished from upstream its level would fall as power was generated. A low water level in the reservoir indicates:

- [ ] increased potential energy
- [ ] decreased potential energy
- [ ] increased kinetic energy
- [ ] decreased kinetic energy

Question 2

Deduce: Water near the dam's intake pipes has the weight of all the water above pressing down on it, so the water is forced into the intake pipes. Which of the following are true?

- [ ] The higher the water level in the reservoir the greater the speed of the water flowing in the intake pipes.
- [ ] The higher the water level in the reservoir the greater the kinetic energy of the water flowing down the intake pipes.
- [ ] The higher the water level in the reservoir the lower the kinetic energy of the water flowing in the intake pipes.
- [ ] The reservoir water level makes no difference to the kinetic energy of the water in the intake pipes.

Question 3

Label: Label the main types of energy involved in hydroelectric power generation in the numbered boxes below.
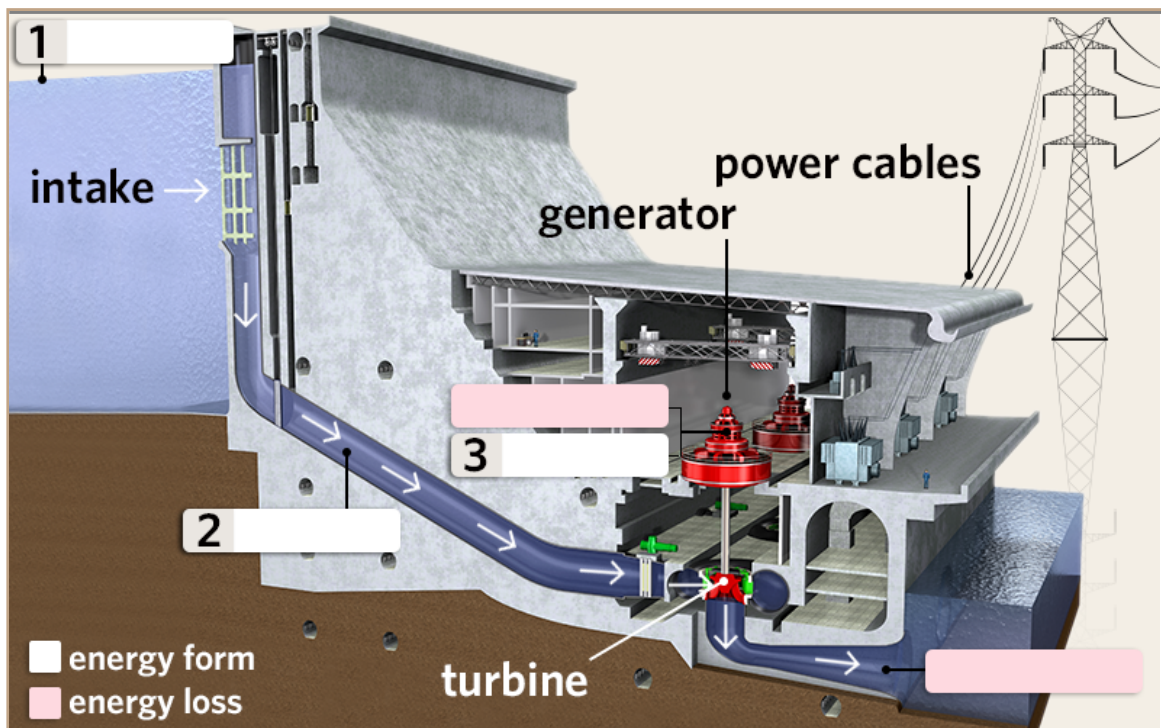
📝 Question 4

Infer: Hydroelectric dams are 90% or more efficient, meaning 90% or more of the original energy is converted into the final, usable form. But that still leaves up to 10% that isn't transformed. In the sketchpad the locations of the two main sources of waste energy are marked with pink labels. Can you guess the forms of the waste energy from these locations? Write them in.

Hint 1: one kind is created by friction in a machine.

Hint 2: if you can't think of the second one, go to the next question – it might help.

📝 Question 5

Explain: 1. Does the water coming out from the turbines move at the same speed as the water going into them? Explain your answer with reference to the energy transformation occurring in the turbines.

2. Do the turbines use all of the energy in the water? What would happen if they did?

Wave power

Although most hydro power has traditionally come from the damming of rivers, other ways of getting usable energy from water are becoming increasingly important. The *Cosmos Newsblog* post describes one example. The principle is described in this video.

📝 Question 6

Describe: In your own words, describe the energy transformations involved in the "duck gen" electricity generator.

Systems of this type typically have an efficiency of around 80%. Suggest where the remaining 20% might go.

📋 Question 7

Research: The law of conservation of energy means that we can never create energy out of nothing. To supply our needs we need to be able to extract energy efficiently from the sources we already find around us. But all of these methods have some negative impact on the environment.

Search for information about one of the types of hydro power – traditional dams, tidal power or wave power. What impacts can it have on the environment? How much risk do you think these pose, and what measures can be taken to minimize them?

Present the results of your search in the project space below in text, tables, graphs, videos, infographics, etc.

Apply: Energy Conservation

Energy changes in a virtual skate park

Intro

1. Open the *Energy Skate Park: Basics* simulation here, and select **Intro**.
2. Select **Bar Graph** from the menu. The graph shows the skater's levels of gravitational potential, kinetic and thermal energy, as well as the total of them all.
3. Drag the skater up and down. While you don't release her the total energy consists only of potential energy. See how it rises and falls with her height above the ground.
4. Move the skater to the top of the screen between the ramp and menus, as shown on the right. Release and watch how the energy levels change when she falls to the ground.
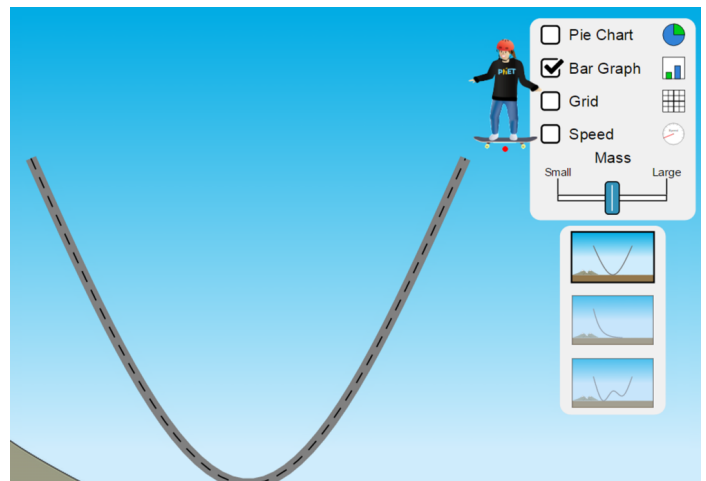
Question 1

Observe: Select **Slow Motion** and then **Restart Skater**. The same fall is repeated so you can observe the changes in energy levels more carefully. Describe these changes.

Question 2

Explain:

1. Press the blue Pause button.
2. Drag the skater to the top left rim of the ramp. Notice that all of her energy is potential.
3. Press the Play button and watch the energy changes in the bar graph as she goes back and forth.

This section of the simulator has no friction or air resistance. Explain why the skater rises to the same height on each side of the ramp.
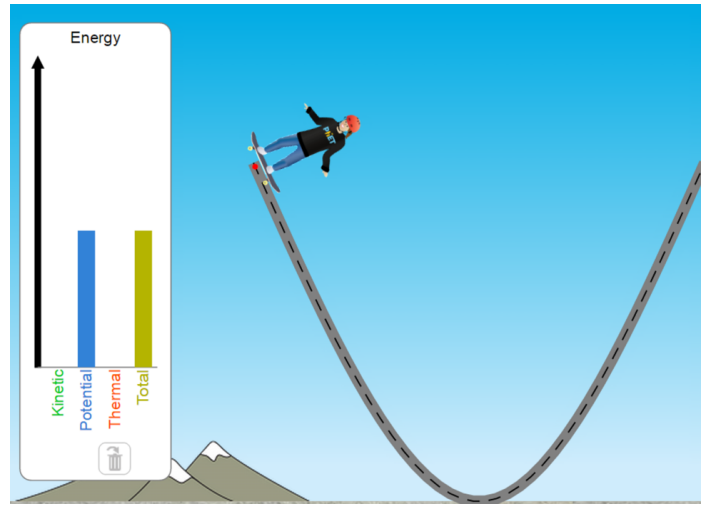
Question 3

Test: Test Galileo's hypothesis by changing the shape of the ramp to the double curve and releasing the skater from the top left. Does she reach the same "stop height" as in the single curve ramp? Why do you think the shape of the ramp doesn't matter?

Friction

1. Now select **Friction** from the main menu at the bottom of the screen. This section is more realistic because the forces of friction and air resistance are taken into account.
2. Select **Bar Graph** and **Grid** from the top right menu, press the Pause button.
3. Drag the skater to the top left position on the U-shaped ramp.

📝 Question 4

Calculate: Use the grid to measure the initial height of the skater. Assuming that she has a mass of 55 kg and that the gravitational field strength, g, is 9.8 m/s^2, calculate her initial potential energy.

📝 Question 5

Compare: Select **Slow Motion** and then press Play. Pause when the skater reaches the highest point on the opposite side of the ramp.

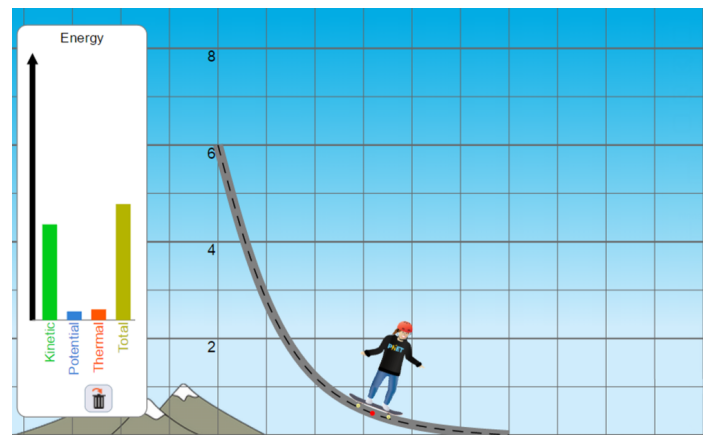Calculate her potential energy now. How much energy has she lost?

📝 Question 6

Explain: Explain the difference between your results from Questions 4 and 5.

📝 Question 7

Deduce: Select the down ramp, shown at right. Make sure the **Bar Graph** is still open.

If you send the skater down the ramp she will go off the screen. How do you know when she has stopped moving?
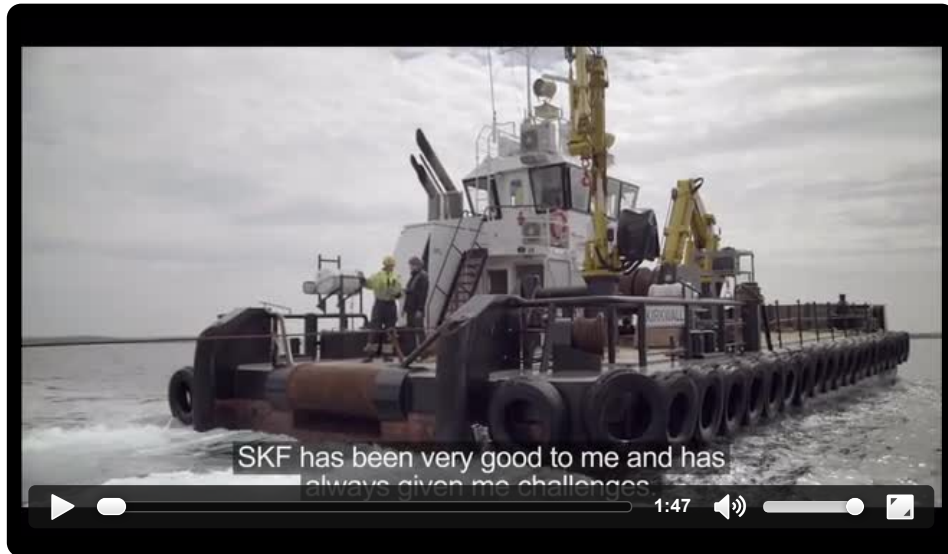

Playground

Select **Playground** from the main menu. Drag up sections of ramp and connect them to design an exciting ride. Compare with your classmates.
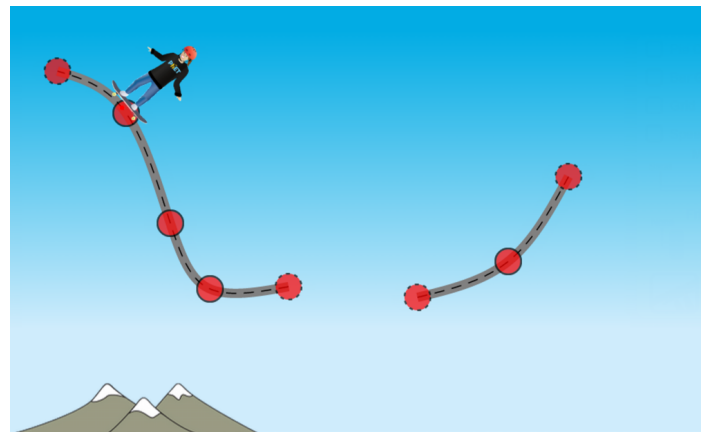
Career: Energy Conservation

SKF has been very good to me and has always given me challenges

1:47

Question 1

Reflect: The video shows that pursuing a career in science and engineering doesn't necessarily mean working in a lab in a white coat.

Write down a few other science-related jobs that involve working outdoors – search the internet if you need to. Would you prefer to work in a lab or outdoors? Why?