Purpose

In the previous activities of this unit you have seen that during a contact push/pull interaction, when a single force acts on an object, its speed either increases or decreases, depending on whether the force acts in the same direction as its motion, or opposite to it. Do you think a force of any strength will produce the same effect on any object, or will the motion of the object depend on its mass and the strength of the force?

If you were to continuously push your friend on his well-oiled skateboard, would his motion depend on how hard you pushed? If so, how? Would his motion depend on how much mass he has? How do you think these two factors would affect his motion if you were to push against him in the opposite direction to his motion as he moves?

When a force acts on an object, how is the object's motion affected by the strength of the force and the object's mass?

Initial Ideas

In Activity 2 of this unit you investigated the motion of a cart while it is being pushed along the track by a fan unit and saw that its speed continuously increases. Suppose you were to repeat the experiment again with two otherwise identical carts, one of which has a fan-unit that pushes with a stronger force than the other.
Assuming the effects of friction are negligible, would the motion of the two carts be exactly the same, or different in some way?

Sketch (and label) two lines on the blank speed-time graph for the two otherwise identical carts being pushed by a ‘weaker’ and a ‘stronger’ force.

Briefly explain the reasoning that led you to draw the graphs the way you did.

Participate in a class discussion about this question and make a note of any ideas or reasoning different from those of your team.

Collecting and Interpreting Evidence

Exploration #1: How does force strength affect speeding up and slowing down?

You will need:

- Low-friction cart and track
- Fan unit
- Access to a Motion Sensor connected to a computer
- Color pencils
- Spare batteries and dummies (as needed)
STEP 1: In Activity 2 you established that a fan-unit provides a constant strength push on the cart. For this experiment you will need to have a way of changing the strength of the fan-unit’s push on the cart. For some fan units this can be accomplished with a built-in switch. For others you can change the number of batteries that are used to power the fan unit. Your instructor will tell you which method to use in your particular class.

Open the Motion sensor data collection file for this experiment. Make sure the fan unit is set to provide a ‘weaker’ force (by selecting the ‘low setting, or by using only two real batteries to power it). Place the cart about 20 - 30 cm from the motion sensor so that the fan will push it away from the sensor. Turn the fan unit on and hold the cart steady. Start the data collection and then release the cart.

What happens to the speed of the cart as it moves? Why is this?

STEP 2: So that it is available for comparison you should now store the current Motion Sensor data on the computer. (See the How to use the Motion Sensor Appendix for instructions on how to do this, or ask your instructor).

Now adjust the fan unit so it is set up for a ‘stronger’ force (either by selecting the appropriate setting or by adding two more real batteries) and repeat the experiment.

Using different color pencils, sketch the two speed-time graphs. Label each one according to how strong the force was.
What is similar about how the speed of the cart behaves, even when different strength forces are acting on it?

Which of the forces, stronger or weaker, caused the speed of the cart to increase at a higher rate? Explain how the lines on the graph show this.

**STEP 3:** Clear all the Motion Sensor data on the computer. (See *How to use the Motion Sensor* for instructions on how to do this, or ask your instructor.) Your fan should currently be set to provide a ‘stronger’ force. Now, place the cart about 20 - 30 cm from the motion sensor, this time so that the fan unit will push it *toward* the sensor. Turn the fan on and hold the cart steady. Start the data collection and then give the cart a quick push away from the sensor. *Stop the cart just as it starts to move back toward the sensor.*

How does the speed of the cart behave *after* your quick push? Why is this?

**STEP 4:** Store the Motion Sensor data and then repeat this procedure using only two batteries to power the fan unit. Try to make sure the speed of the cart just after the push is about the same as it was in STEP 3. (*To check this, make sure both graphs rise to about the same maximum value at about the same time.*)
Activity 5: Changing Force-Strength and Mass

Using different color pencils, sketch the two speed-time graphs. Label each one according to how strong the force was.

What is similar about how the speed of the cart behaves after the initial push, even when different strength forces are acting on it?

Which of the forces, stronger or weaker, caused the speed of the cart to decrease at a higher rate? Explain how the lines on the graph show this.

STEP 6: You already saw earlier in this unit that when a single force is applied to an object, its speed will change in some way. (It will increase if the force is in the same direction as its motion, and decrease if the force is in the opposite direction to its motion.) Now you have investigated how the strength of the force affects the rate at which the object’s speed changes?

How does the rate at which the speed of the cart changes (increases or decreases) depend on the strength of the force acting on it? Does the

---

1 Scientists use the term ‘acceleration’ to refer to any change in speed (increase or decrease) and define an object’s acceleration to be the rate at which its speed changes. However, in everyday use the word ‘acceleration’ is usually understood to mean only an increase in speed. Therefore, to avoid confusion we will not use the term ‘acceleration’ in the PET activities.
speed change at a higher, or lower, rate when a stronger force is applied? How can you tell this from the speed-time graphs?

Check your answers to this question with at least two other groups and try to resolve any differences.

**Exploration #2: How does mass affect the rate at which speed changes?**

You will need (share with another group, if necessary):

- 2 Low-friction carts and 2 tracks
- 2 Fan units
- Extra masses (metal bars)
- Ruler
- Access to a computer with internet connection

**STEP 1:** Place the two tracks side-by-side. Mount a fan unit on each of the carts and place one on each track. Make sure you have two fan units that provide about the same strength of push. To do this, turn on the fan units, line up the carts side-by-side (on separate tracks), and let them go at the same time.

Assuming the two carts are identical, what should happen if the fan units are of about the same strength?

If the two fan units do not appear to have close to the same strength try changing the number of batteries, or try different fan-units.
**STEP 2:** Now, put two of the metal bars on one of the carts. (Make sure they will not interfere with the fan blade.) Again, hold the carts side-by-side, turn on the fan units, and release both carts at the same time.

Describe the motion of the two carts. If they were in a race, which one would win? (After the experiment, leave the tracks and carts where they are as you will need them again later.)

When the same strength force acted to speed up the two carts, which cart increased speed at a faster rate, the one with less mass, or the one with more mass? How do you know?

**STEP 3.** In Activity 3 you also used a fan-cart, but this time gave it a quick push to get it started and then used the fan unit to exert a continuous force in the direction **opposite to its motion.** This caused the cart to slow down, stop momentarily, and then move back toward its starting position, speeding up as it did so.

Suppose you took your two carts, with equal strength fans and different masses, and gave both carts a push away from you so that they start moving side-by-side at the same speed (with the fan units pushing **opposite** the direction of motion)

Which cart do you think would be the first to slow to a stop and start moving back toward you – the one with **less mass**, or the one with **more mass**, or would they both be the same? Explain your reasoning.
STEP 4: Return the carts (one should still have its added mass) to the starting point and turn them around so that the fan units will push them in the opposite direction. Turn the fans on, and give both the carts a quick push, against the fans, to start them moving at the same speed.

To have both carts moving at about the same speed, one person can push both of them, using a ruler, as shown in the top view here.

Repeat the experiment three times, using a different person to push for each trial.

Which cart slows to a stop and reverses direction first, the one with less mass, or the one with more mass? Does your observation agree with your prediction in STEP 3?

When the same strength force acted to decrease the speed of the two carts, which cart decreased at a faster rate, the one with less mass, or the one with more mass? How do you know?
In both cases you have seen in this exploration (speeding up and slowing down) which cart’s speed changed at a higher rate when the same strength force acted on them, the one with less mass, or the one with more mass?

**STEP 5:** In STEP 2 you held a ‘race’ between two carts that had different masses but the same strength force pushing on them. Now, suppose you wanted to make a race between the two carts end as a tie.

To make the race a tie, what would you have to do to the strength of the fan unit pushing on the more massive cart? Explain your reasoning.

Now suppose that one of your carts had a total mass of 6 kg while the other was only 2 kg, but that both fans applied a force of 20 N to them.

Watch *UFM-A5-Movie 1*, which shows a simulation of this arrangement in which both fans have the same force strength of 20 N.

Which simulator cart (Cart 1 or Cart 2) has a mass of 6 kg and which has a mass of 2 kg? How do you know?

To make both carts increase speed at the same rate, and hence make the race a tie, what strength force should the fan acting on the 6 kg cart push with? (Remember, its mass is three times greater than the lighter cart.) Explain your reasoning.
Now watch **UFM-A5-Movie 2**, in which the simulation will be run four times. Each time the strength of the fan force being applied to the 6 kg cart will be set to a different value. (The force strength on the 2 kg cart will be kept at 20 N throughout.)

🔍 For which value of the force strength on the 6 kg cart does the race between the two carts end in a tie? Does this agree with your prediction above?

When the carts increased speed at the same rate their masses were not the same, so it cannot be just mass that determines the rate at which speed changes. Similarly, the force strengths were not the same, so it cannot be just the force strength that determines the rate at which speed changes.

✍️ Discuss with your group and try to determine some way of combining mass and force strength that gives the same value for both carts when the race ended in a tie.

**Summarizing Questions**

✍️ First discuss these questions with your team and note your ideas. Leave space to add any different ideas that may emerge when the whole class discusses their thinking.

**S1:** When a single force acts on an object, how does the rate at which its speed changes depend on the strength of that force? Is this true for both increasing and decreasing speed? What evidence supports your answer?
S2: To the right is a speed-time graph for a cart that was given a quick push along the track and then gradually slowed down. Which force do you think was stronger, the initial push, or the one that slowed it down? How do you know?

S3: How does the mass of an object affect the rate at which its speed changes, while a force acts on it? What evidence supports your answer?

S4: At a practice session a soccer goalie is practicing rolling a soccer ball along the ground. To improve his strength he also practices rolling a bowling ball. The coach measures the speed of the both balls and sees that, when the goalie pushes as hard as he can, the soccer ball has a speed of 15 m/s just after it leaves the goalies’ hands, but the bowling ball has a speed of only 2 m/s.

Write an explanation for why the bowling ball’s speed is much less than the soccer ball’s speed, just after they left the goalie’s hands. Assume the goalie applied the same strength force to both balls, for the same amount of time.
Explanation: Why was the bowling ball’s speed much less than the soccer ball’s speed just after the goalie had pushed them both with the same strength force, for the same amount of time?

Describe the Situation using a diagram: (Draw two separate force diagrams, one for each ball at a moment in time during the push.)

Write the narrative: (Use the idea you developed in this activity about how the effect of a force on an object depends on the object’s mass.)

S5: In this unit you considered mostly cases in which you compared the motion of two objects for which only the force strength or the mass was different. But what if you had two objects that both had different masses, and were both acted on by forces of different strengths? How could you predict which object’s speed would change at a faster rate under these circumstances?

Two students were discussing their ideas about a relationship that they could use to help them decide:
In terms of a mathematical relationship, Amara thinks:

$\text{Rate of change in speed} = \text{Strength of force} \times \text{Mass of object}$,

while Han thinks:

$\text{Rate of change in speed} = \frac{\text{Strength of force}}{\text{Mass of object}}$

Do you agree with Amara, Han, or neither of them? What evidence from this activity supports your thinking?
S6: Some students have a race between two different fan carts. Cart A has a mass of 0.5 kg and a fan strength of 0.3 N. Cart B has a mass of 0.7 kg and a fan strength of 0.4 N. Which cart will win the race, and why?

Participate in a class discussion to go over the summarizing questions.

---

2 When the force strength is measured in units of newtons (N) and the mass is measured in kilograms (kg), the units of ‘rate of change of speed’ will be \( \text{meters per second per second} \) \([\text{m/s}/\text{s}]\). These units tell us how quickly the speed (in m/s) will change during one second. For example a ‘rate of change of speed’ of 5 \( \text{m/s}/\text{s} \) means the speed will change by 5 m/s for every second that the force is being applied.